

# metal treatment

Vol. 28 : No. 186

MARCH, 1961

Price 2/6

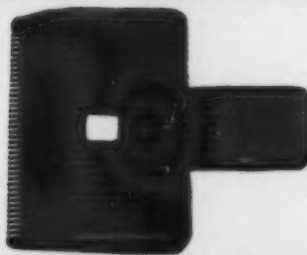
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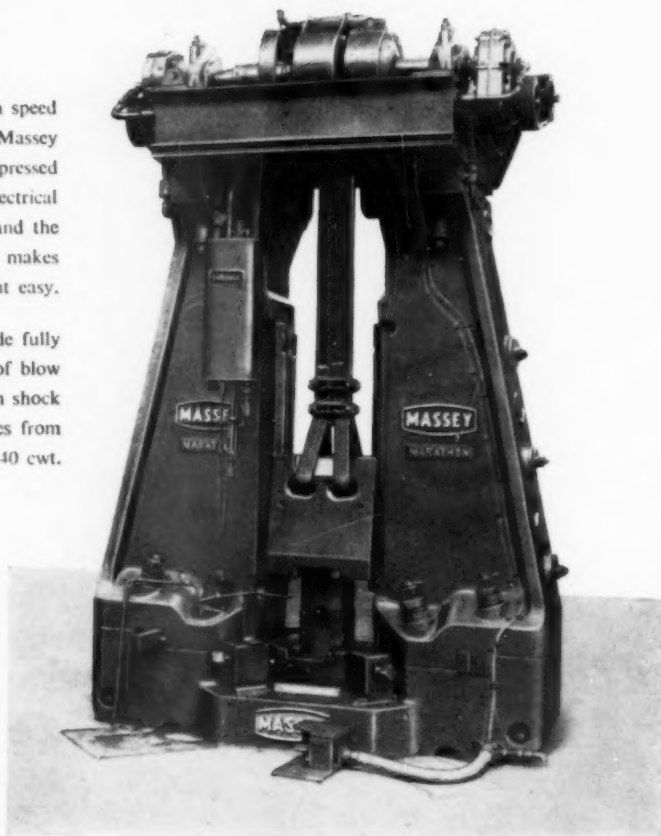
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*Descriptive literature will gladly be sent to responsible authorities upon request to address below*

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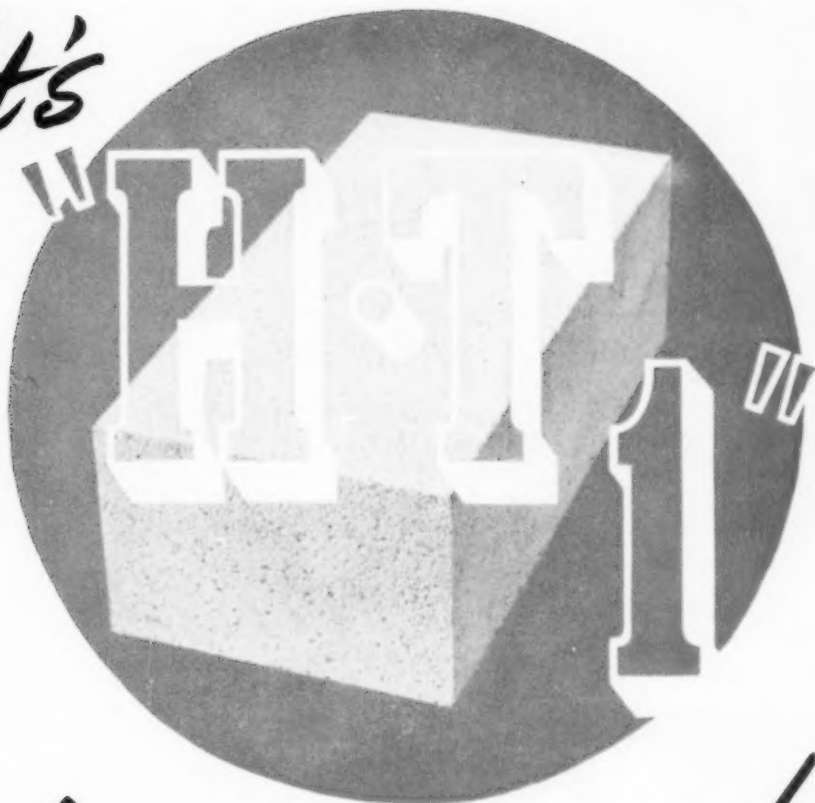
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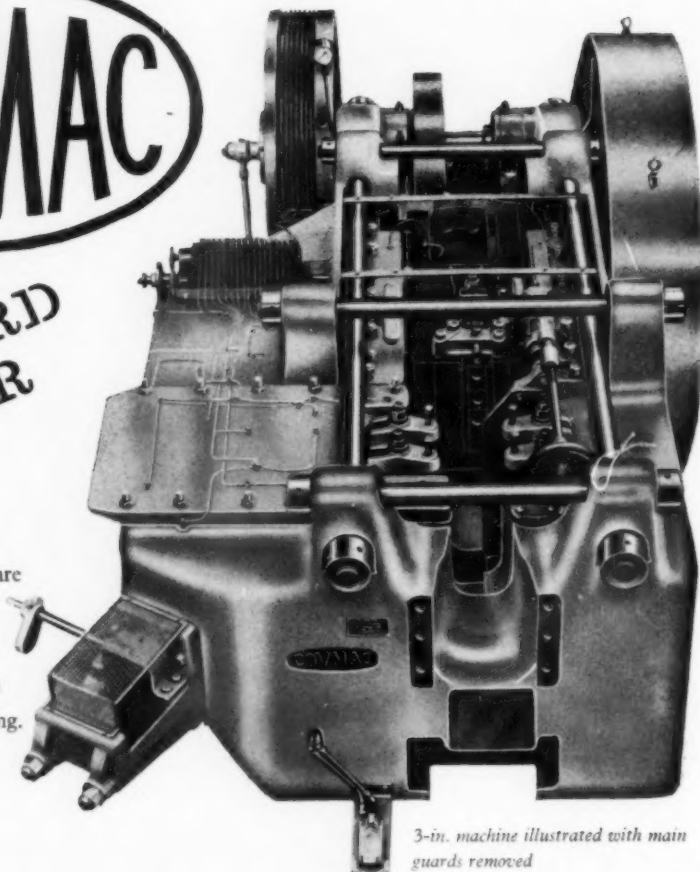
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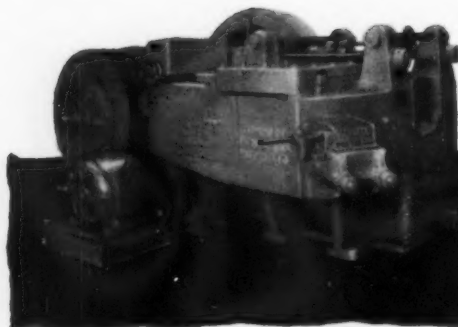
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Covmac Forging Machines are made in nine sizes to take bars from  $\frac{3}{4}$ -in. to 6-in. diameter. Safety devices on all models prevent overloading.



3-in. machine illustrated with main guards removed

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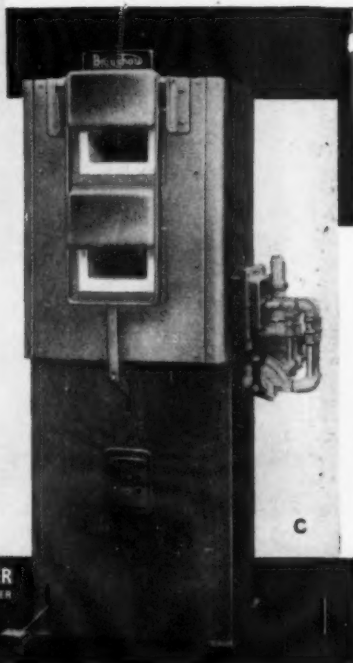
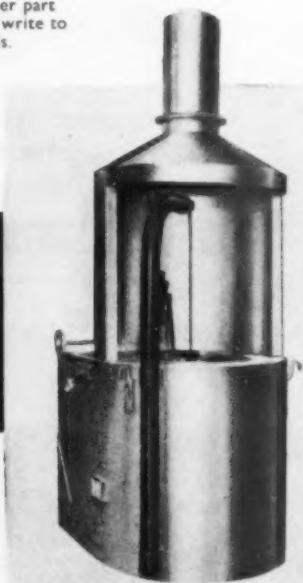
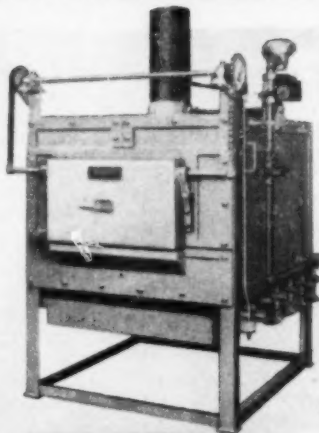
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If you would like information on these or any other part of our range please write to us for further details.



**What the illustrations show:**

A.—'Hynor' Oven Furnace.

B.—Liquid Bath Furnace.

C.—Twin Chambered High Speed Steel Furnace.

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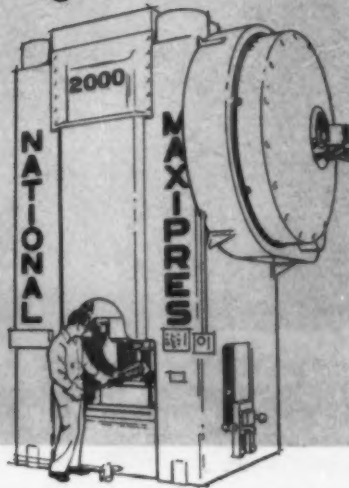
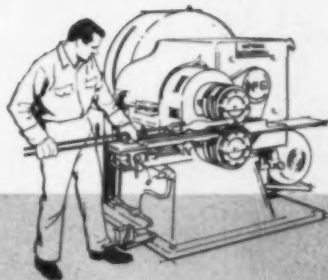
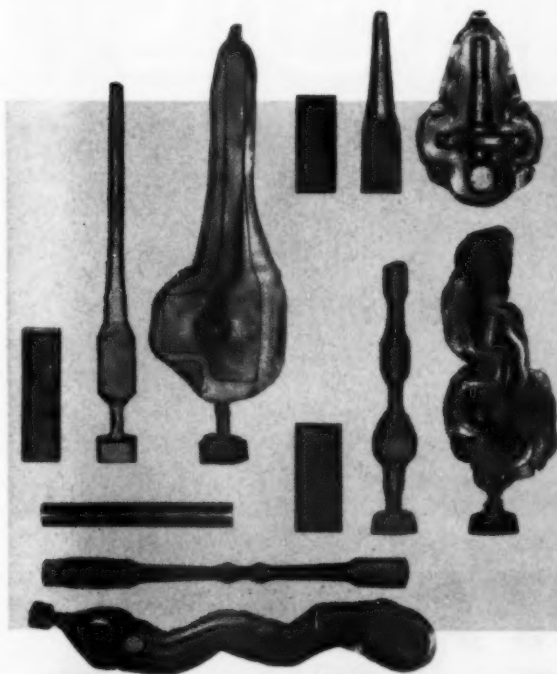
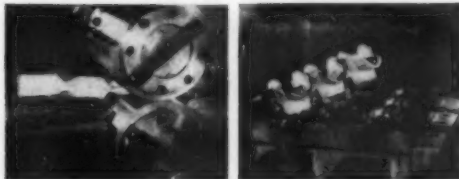
# REDUCEROLL + MAXIPRES = Modern Forging!

Modern forge plants around the world are using the method shown at right:

1. Prepare forging blanks in Reducerolls;
2. Finish forge in Maxipresses on the same heat.

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Bring your prints or forgings to Tiffin or Nurnberg. Let's discuss your plans for automatic or manual forging, but without obligation.



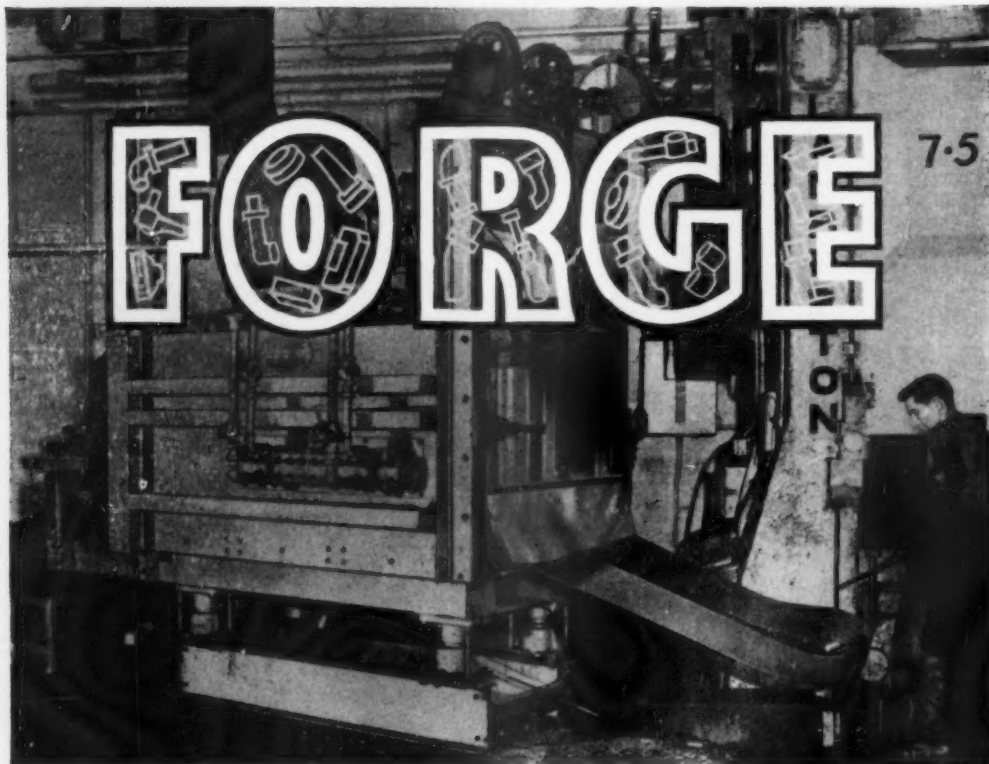
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# **THERMIC** *Mechanised*



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## **FURNACES**

A wide range of standard or tailor-made mechanised forge furnaces is available, Pusher Type - Rotary Hearth Type - Conveyorised Bar End Heating, with GGC scale-free heating system or fired by gas or oil. The photograph above illustrates a small Thermic Magazine Feed Pusher furnace fired by CC Burners. Output: 7-cwts. of small billets per hour.

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(Subsidiary Company of Gibbons Bros. Limited, Dudley)

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The New

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## PRECISION HAMMER

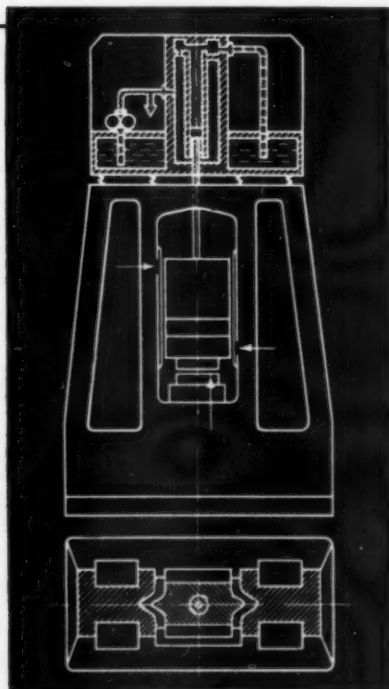
is a short stroke downward pressure hammer with oil-hydraulic rocker drive.

It was developed for mass production of precision forged components and is a natural addition to the Eumuco range of chain hammers of smaller size up to approx. 10 tons.

The experience gained in double shift operation over a period of more than a year has proved that the aim in designing this hammer has been realized.



of  
**MONOBLOC**  
design



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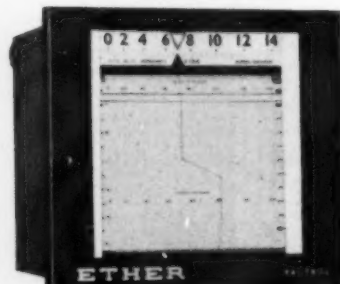
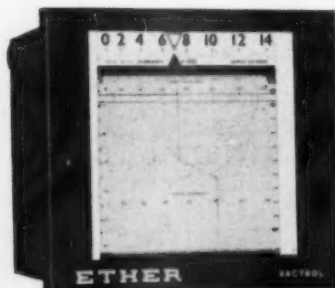
### SERIES 2000

Single-point Potentiometer Recording Controllers

- Type 2000: Two-position on/off control
- Type 2001: Anticipatory control
- Type 2002: Proportioning (electrical) control
- Type 2003: Three-position control
- Type 2004: Programme control
- Type 2005: Proportioning (motorised) control

### SPECIAL FEATURES:

- Interruption of mains supply to instrument automatically shuts down furnace
- 6" calibrated scale
- Standard ranges: 2mV—100mV span; other ranges to order. Changed by plug-in printed-circuit unit
- Standard pen speed: 2 secs. across chart; 1 sec. or 4 secs. also available
- Chart life: 1 month at 1 inch per hr.



Type 2000  
Two-position on/off control

Type 2002  
Proportioning  
(electrical)  
control

Type 2005  
Proportioning  
(motorised) control

**\* SIMPLICITY OF DESIGN \* EASIER RANGE CHANGING  
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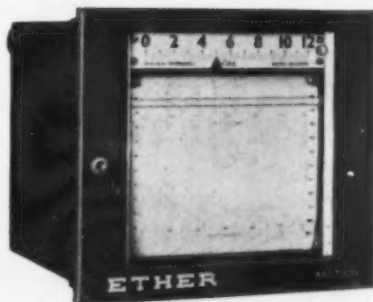
Type 2052: Two-point record

Type 2053: Three-point record

Type 2056: Six-point record

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- \* Balancing motor totally de-energised throughout printing and indexing cycles
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- \* 6" calibrated scale
- \* Standard ranges: 5mV—100mV span; other ranges to order. Changed by plug-in printed-circuit unit
- \* Pen speed: 2 secs. across chart
- \* Printing speed: 6 secs. per point
- \* Chart life : 1 month at 1 inch per hour



## SERIES 2500

### Single-point Potentiometer Indicating Controllers

Type 2500: Two-position on/off control

Type 2501: Anticipatory control

Type 2502: Proportioning (electrical) control

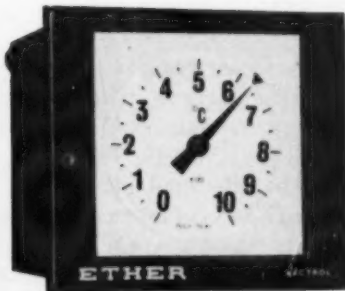
Type 2503: Three-position control

Type 2504: Programme control

Type 2505: Proportioning (motorised) control

#### SPECIAL FEATURES :

- \* Interruption of mains supply to instrument automatically shuts down furnace
- \* 18" calibrated scale
- \* Bold easy-to-read scale and pointer
- \* Standard ranges: 5mV—100mV span; other ranges to order. Changed by plug-in printed-circuit unit
- \* Response speed: 2 secs. across scale



Type 2500  
Two-position on/off control



Type 2502  
Proportioning  
(electrical)  
control

Type 2505  
Proportioning  
(motorised)  
control



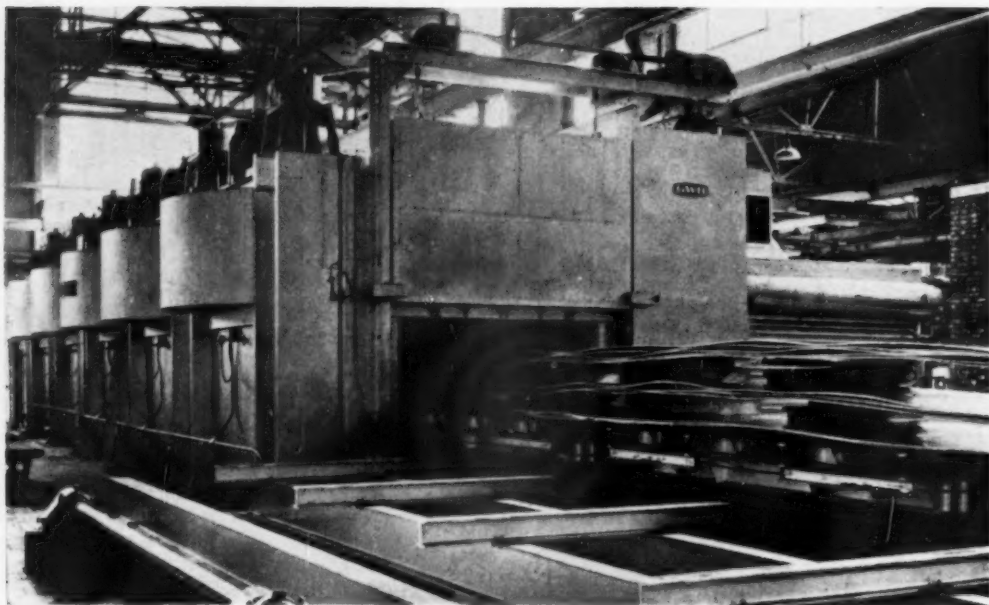
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*Batch Type Furnace installed, with slow cooling chamber at right, at Northern Aluminium Co. Ltd. for annealing aluminium slabs prior to cold rolling.*

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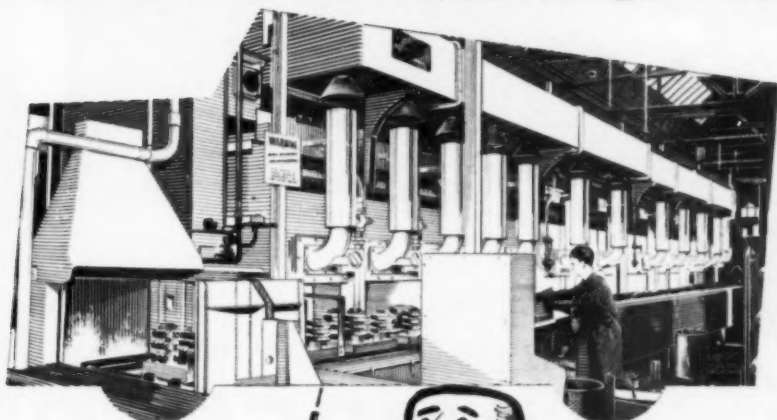


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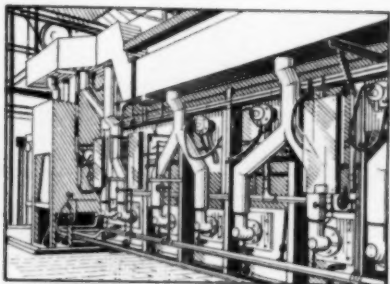
metal treatment  
and Drop Forging

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carries weight in the

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*These illustrations, by courtesy of Ford Motor Co. Ltd, show two of many continuous gas carburizing furnaces installed at their Dagenham factory, using endothermic atmospheres produced from PROPAGAS.*

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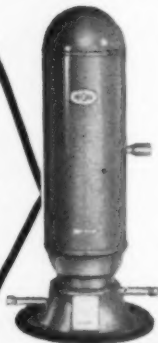
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*For the  
removal of  
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other gases*



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dry  
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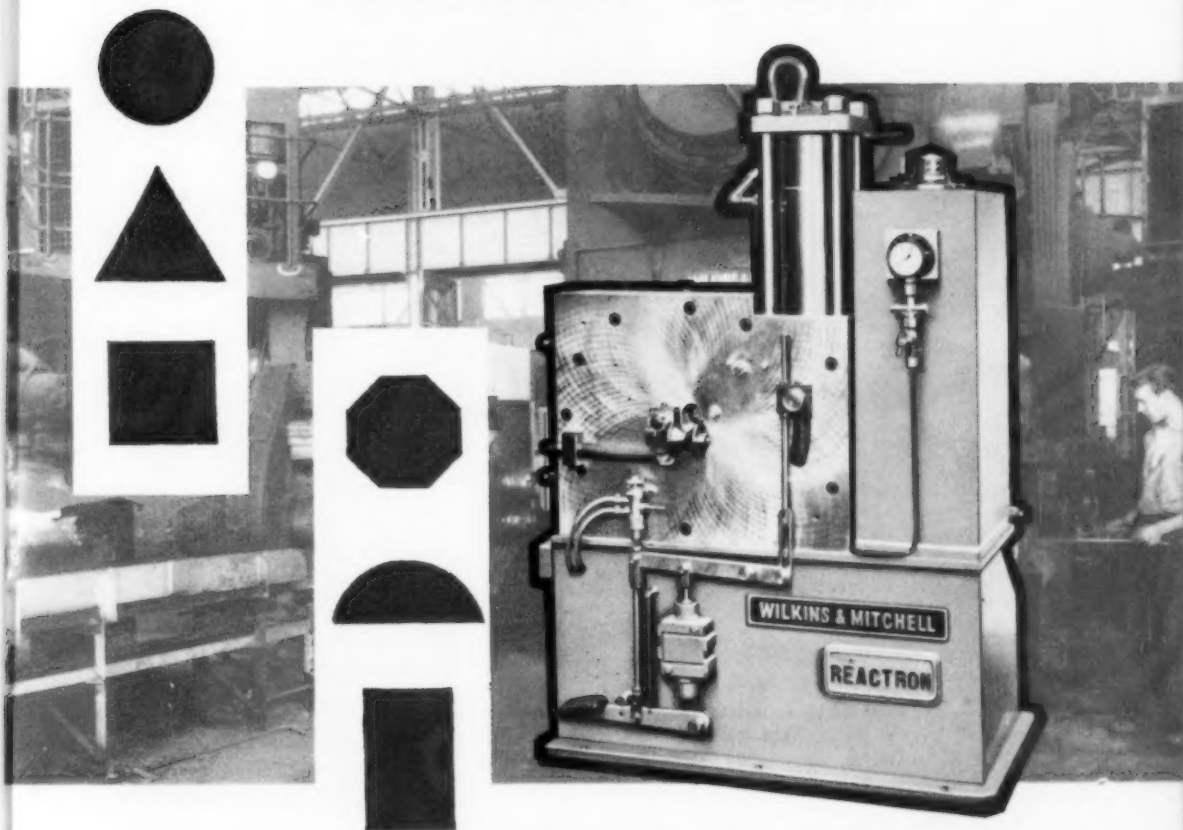
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# metal treatment

and Drop Forging

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## Engineering design

**N**OSTALGIA for the 'good old days,' a remote time when the open road offered the pioneer motorist the challenge of virgin territory still unexplored, may explain something of the present cult of the vintage car. Nevertheless, a large part of the fascination of this branch of antiques, as in many others, lies in the pleasure derived from the recognition of inherently beautiful design. Early machinery of most kinds, from the cross-bow to the first motor car, although betraying vestigial remains of its ancestry, always involves a fundamental step calling for a novel approach to design. Then, as the machine evolves into more complex descendants, the original design becomes overlaid with a hotchpotch of improvements. Superficial 'modernizations' may then be superimposed on the agglomeration, most of them having, of course, no functional reality, and all too easily the result is an abomination such as is sometimes seen masquerading as a 'contemporary' motor car.

There are two main reasons why a casual attitude towards design problems may prove a costly mistake. In our editorial last month, we suggested that the new study of ergonomics could point the relation between operator efficiency and machine design. When the importance to productivity of well-designed equipment becomes more widely appreciated, managements will become more discriminating and favour the manufacturer who gives most prominence to this feature. The other factor concerns the machine manufacturer's own production. Although elaborate retooling of a production line may prove too costly to contemplate, uneconomic processes are sometimes perpetuated when they could be avoided by complete redesign of the final product in the light of newly available materials and methods.

There seems little doubt that a big change in attitude to design questions is taking place today. The Council of Industrial Design reports that enquiries from capital-goods makers regarding the use of designers has increased threefold in the last three years, and it is not hard to see what has triggered off this reaction. No manufacturer today, whatever his product, can afford to ignore overseas' markets, and it is a fact that most of these overseas' markets are more design-conscious than our more traditional home users. The claim is made by some makers that much of our machinery could be improved, and thus become more competitive in foreign markets, if the home-user overcame some of his out-of-date prejudices. If this is so in fact, then it seems high time that a programme of re-education in industrial design became a national priority. Some public utilities have given a lead in their own design of equipment, but much still remains to be done. Cases have been cited where foreign purchasers specify the required appearance of capital equipment in relation to the modern layout and architecture of their plants. Design thus takes on an integrating quality which affects the whole conception of the factory and its equipment. It seems that a meeting point between industrial designers and architects needs to be created—perhaps the COID could extend its present courses to include this wider conception.

There is another aspect of design influence which should, perhaps, be mentioned. More recently established industries, such as notably the electronics industry, are less moulded by past influences and traditional procedures. Thus, in many cases, they set the pace for other manufacturers and gradually spread improved trends of design. However, useful though this is, it is too slow and unreliable to depend on as a means of general improvement. We must recognize that neglect of design could ultimately have just as disastrous effects on our export position as would neglect of any other important technical factor.

## Drop Forging Research Association

A LITTLE OVER a year ago we made the first announcements of the proposed co-operative research association for the drop-forging industry. Much hard work has gone into making the proposition an actuality, and there is little doubt that the whole industry in this country will benefit from the efforts of those who made this possible. The individuals who played such a large part in this, and the NADFS who sponsored the formation, are to be congratulated on their foresight and disinterested activity.

Support from the industry has already been forthcoming, according to Mr. W. E. Golcher, chairman of the DFRA, in a short report given at the a.g.m. of the NADFS last month by permission of the president of the NADFS. Mr. Golcher pointed out that the generosity of the Government grant would be in direct proportion to the response of industry, and so offered a real incentive to those who wished to see the maximum use made of the facility.

It is certain that only the most complacent firm could imagine that it is able to withstand the impact of present-day competition from rival methods and materials without engaging in the most active research at its disposal. Co-operative research makes possible for the small firm what would otherwise be the monopoly of the industrial giants.

### Research director

The Council of the DFRA has appointed Mr. P. H. R. Lane, B.Sc.(Eng.), A.I.M., A.M.Inst.W., to be the first director of research. Mr. Lane took up his appointment in Sheffield on March 1. For the past 12 years he has been with the British Welding Research Association where he was head of the Members' Service Department.

Mr. Lane was educated at Alleyn's, Dulwich, and Strand School, Elm Park. He obtained an honours degree in metallurgy at the University of London and subsequently joined the staff of the



Mr. P. H. R.  
Lane

BWRA. He was first engaged in metallurgical work on the weldability of low-alloy high-tensile steels. In 1950 he transferred to the engineering section to work on the design of pressure vessels and pipeline components, and for five years was in charge of the department dealing with this work. During this period he was also associated with work on the brittle fracture of steel plates and on the fatigue strength of welded components.

In 1957 he returned to metallurgical work as deputy chief metallurgist of BWRA, in charge of all ferrous metallurgical investigations. In 1959 he was appointed to the new position of head of the Members' Service Department at BWRA. This department is responsible for all contacts with the members of the Association.

Mr. Lane is an Associate of the Institution of Metallurgists and an Associate Member of the Institute of Welding. He has published many papers on both the metallurgical and engineering aspects of welded fabrications and also on the techniques of experimental stress analysis.

### Automatic profiling by tape control

At the Woodside (Leeds) Works of British Oxygen, milling production times have been substantially reduced by using automatic computer-controlled techniques. Intricate profiles which formerly would have been expensive and lengthy to copy from templates can now be machined in one-tenth of the time with the aid of a Cincinnati milling machine fitted with Ferranti controls.

Typical of many computer-controlled milling operations at Woodside is one where waveguide blocks, designed by E. K. Cole Ltd., are machined in light alloy

to within tolerances of less than one-thousandth of an inch. The magnetic tape which controls the whole milling sequence is accurate to within 0.0002 in. Risk of the prescribed limits being exceeded are overcome by an automatic cut-out of the machine. The amount of scrap is therefore reduced to a minimum. With the computer technique less afterwork and fitting is necessary than with previous methods.

The computer-controlled milling machine—one of six in the United Kingdom—is also used for cam profiling and for stack milling W.D.S. tooling aids produced by British Oxygen at Woodside.

# Forging research in Sweden

## *The research laboratory at Eskilstuna*

ERIK THOLANDER

*Examples of current work on forging research were given by the author in his exposition in the forging laboratory at Eskilstuna during the last NADFS Technical Convention at Droitwich. Mr. Tholander is head of the department for research and development of forging practice within the large association, Sveriges Mekanförbund, which represents the engineering industry in Sweden*

ALTHOUGH the forging industry in Sweden has a long history so far as the production of wrought iron and steel is concerned, the drop-forging industry itself is not very old. Most Swedish drop forges still remain as sub-divisions—and small ones—of engineering industries producing drop forgings for their own needs. It seems, however, that there is an increasing tendency to change this old structure as one firm after another decides to shut down its own forge when having to choose between the two alternatives—modernizing the forge or shut-down and buying the forgings on the market. As a result, a few forges are growing rapidly and are installing new equipment in order to increase production of drop forgings for other firms.

The size of the Swedish output of forged products is not known exactly, but last year we estimated a rough figure of about 80,000 metric tons for the total output of forged steel. Of that figure some 35,000 tons may have been drop forgings, about 20,000 tons of other light forgings and the remainder is thought to have been heavy press and hammer forgings. One-third to one-half of the 35,000 tons is believed to have been used within the same firms which forged them.

Because most forges belong to, or are connected with, companies within the engineering industries, there is no separate organization for the forging industry. In fact, our 'forgers association' is a sub-division of the big association 'Sveriges Mekanförbund,' which represents all the metal-working industries, including foundry and forging, within the top organization 'Sveriges Industrieförbund.' Sveriges Mekanförbund has about 850 members, employing approximately 220,000 persons, of which some 75% are workers. The number of forges is about 175 with some 1,500 forging workers. Our department for forging

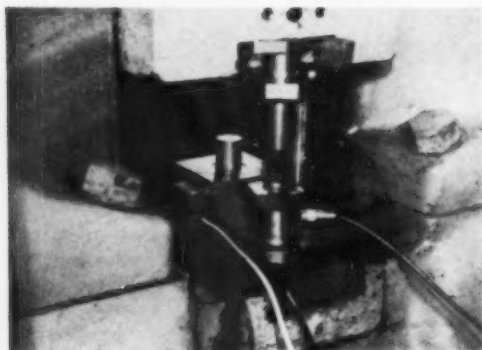
practice — the official English translation was changed a year ago from 'research' to 'practice' — was started in 1954 and moved from Stockholm to Eskilstuna in 1956.

Several factors determined the transfer of the forging department to Eskilstuna. The town has a very old metal-working industry, with many traditions as a forging industry. Geographically, the position is conveniently central, with a large number of forging member firms within a distance of two or three hours by car or by train. There is also a technical school with a new building, where it was possible to install the forging laboratory and office. There are plans to increase the educational and training facilities at this school and, if these plans can be realized, it is hoped that in a few years Eskilstuna will become the Swedish centre for forging and other plastic deformation techniques both in education and research.

### **The forging laboratory and its equipment**

The total floor area, roughly 1,500 sq. ft., is divided into one big and two small rooms. The following machinery has been installed: one board drop hammer (1,000 lb.) and one air hammer (200 lb.) for preforming, both of them installed with coil-spring suspensions and hydraulic shock absorbers. There is also an eccentric trimming press (63 tons) and other smaller machines for drilling, milling, sawing, etc. For heating there is one oil-fired furnace and one electric furnace fitted with Crusilite elements, both automatically temperature controlled by means of thermocouples and electrical recorders.

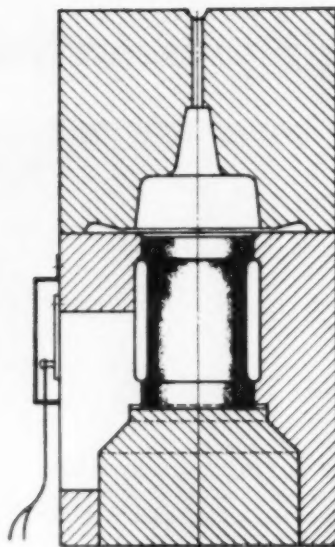
For measuring of pressure variation and tool movement during the short period of a forging blow we have recently built special electronic measuring equipment (figs. 1-2). The system



1 Arrangement of the pressure and movement transducers in the board drop hammer

consists of two transducers, one for pressure and one for tool movement, both of which are connected to a double-beam cathode-ray oscilloscope, the first directly and the second via a carrier bridge. The curves on the oscilloscope screen are recorded photographically by means of a plate camera or a rotating drum camera alternatively, the maximum speed of the latter being about 150 ft./sec. The method has proved to be highly sensitive and works with great accuracy up to a high amount of compression stress, maximum 150 kp./mm.<sup>2</sup> (213,000 lb./sq. in.).

The laboratory is meant to serve both for research work on forging techniques and heating as well as for the training and education of engineers and other technicians for the forging industry.



2 Section through the pressure transducer and an experimental upper die. On the middle of the central, cylindrical steel body are mounted strain gauges. The blank is placed directly on the upper end surface of the measuring body

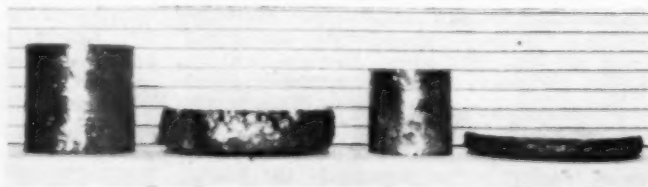
### Research on the forging process in open and closed dies

The equipment just described has been used in two series of forging tests on lead, the first with plain tools for the upsetting of cylinders and the second with closed dies. The central idea of the

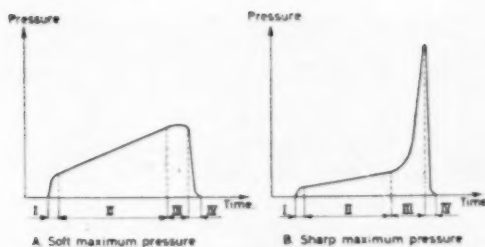
TABLE 1 Specimen dimensions, upsetting time, pressure and stress by upsetting cylinders of various size

Test No.	Size of the blank, mm.	Weight of blank, g.	Final size, mm.	Time, ms.	Final pressure, tons	Final stress, kp./mm. <sup>2</sup>
P 38	φ50 × 50.0	1,220	φ82 × 18.8	11.5	13.3	6.8
P 39	φ40 × 39.8	557.9	φ85 × 8.0	10.8	22.8	11.7
P 40	φ33 × 33.0	320.8	φ92 × 3.8	9.0	45.6	23.3
P 41	φ20 × 20.0	67.3	φ(190) × 0.1	6.1	215	110
P 36	φ50 × 7.9	171.2	φ105 × 1.1	2.2	105	53.5
P 35	φ40 × 12.6	178.5	φ99 × 1.2	3.5	107	55.0
P 34	φ33 × 19.0	183.4	φ99 × 1.5	5.2	97	49.5
P 37	φ20 × 50.4	173.7	φ95 × 1.4	14.2	90	46.0

3 Test cylinders of lead before and after the blow in the drop hammer. Original size φ50 × 50 mm. and φ40 × 40 mm. respectively





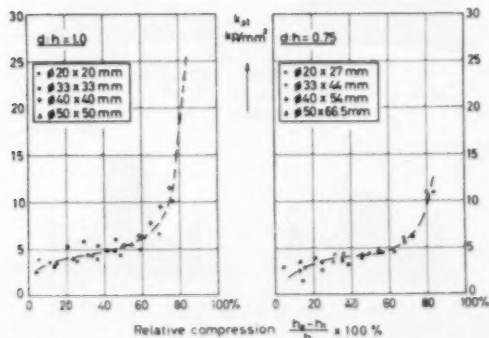


4 Main types of pressure curves by upsetting. Type A with a soft maximum occurs when the energy of the falling tup is too small to compress the specimen to a certain strain limit. Type B with a sharp maximum indicates a 'complete compression' reaching or exceeding the strain limit value. The pressure course has been divided into four parts of which I represents the starting and building up an initial pressure-value, II and III are the real upsetting periods and IV is the unloading period of elastic release of tools and fastening facilities

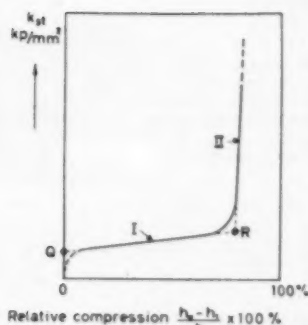
tests was the suggestion that the internal pressure of the metal is an essential factor of the behaviour of the metal during a forging blow.

Upsetting between plain tools. Fig. 3 shows two examples of test pieces before and after the blow. The pressure curve is of two main types as in fig. 4. A 'complete' upsetting course always gives a curve of the right-hand type with a sharp rise in the pressure at the end of the blow. The left-hand curve in fig. 4 can be said to represent a non-completed compression test, because all the energy is consumed by deforming the test piece and no excess energy is left for the final rise in pressure.

Table 1 gives data from tests with test pieces of different sizes. By dividing the measured pressure by the actual average area of the test piece, a figure is obtained for compression stress ( $k_{st}$ ). When this figure is plotted against the relative compression a curve is obtained of the type shown in fig. 5.



6 Stress-strain curves from upsetting experiments with lead cylinders of various sizes but with constant relation diameter to height



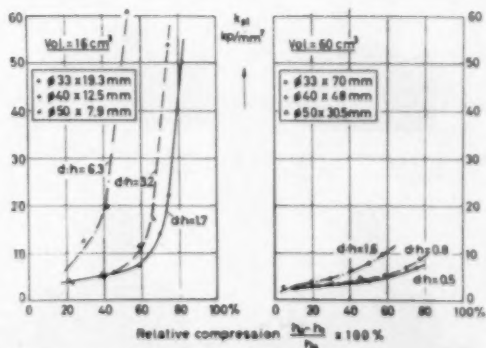
5 The general stress-strain curve found for a 'complete compression' test. The point Q ('compression threshold') indicates the minimum stress necessary to get the compression to start. The point R ('compression wall') indicates a strain limit value over which any further height reduction requires an extremely increased stress

On this curve are two points of general interest, marked Q and R.

Point Q represents the minimum stress required to cause deformation to begin, and it is proposed this be called the 'compression threshold.' This point might be influenced to some extent by tool speed, but in general it will be a characteristic figure for the material of the test piece.

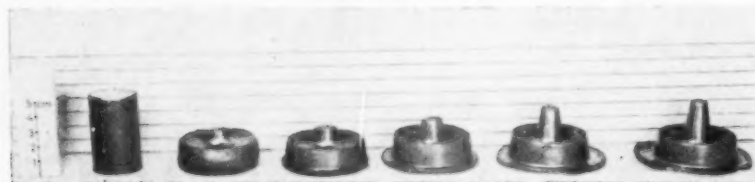
Point R represents a limit of relative compression over which it is necessary to use a very much higher stress to obtain any further compression than before this point. It is proposed to call this point the 'compression wall.' It is to be envisaged as a factor influenced not by the material, but mainly by the shape of the test piece.

Figs. 6-7 show how the compression stress varies



7 Stress-strain curves from upsetting experiments with lead cylinders of various shape but with constant volume. At the series with big pieces (right) the energy of the falling tup has been too small to give 'complete compression' but the trend is clearly similar to that in the left diagram with smaller pieces

8 View of blank and component at four stages of one single blow. Upper die has been stopped on four different heights without closing dies (using steel disks of different thickness)



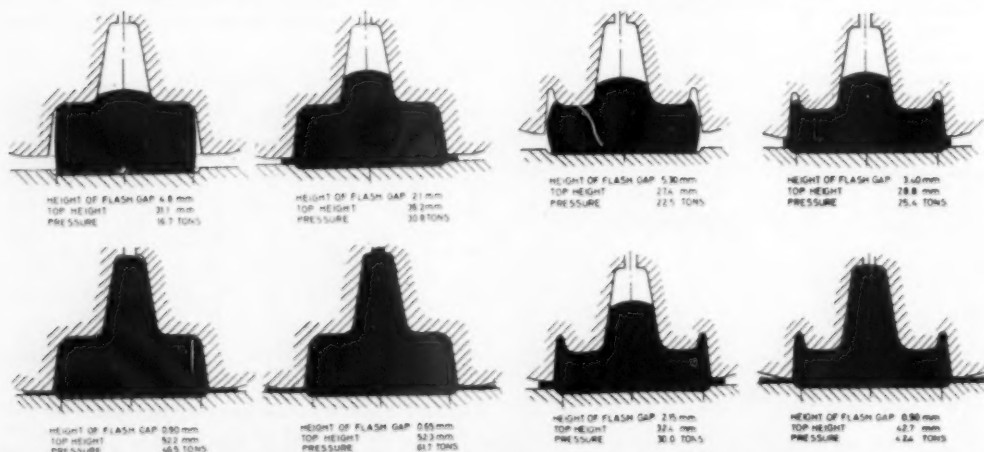
10 View of blank and component at five stages of one single blow made in the same way as in 8

when (a) the form of the test piece is held constant and (b) when the form is varied with the volume held constant. The conclusion is that the original test-piece form has a very great influence on the compression resistance of the material to a high degree of relative compression, consequently large-diameter flat test pieces offer greater resistance than small-diameter tall test pieces. In other words the compression wall moves to less and less relative compression as the shape of the blank flattens.

*Experiments with closed dies.* The other series of tests was made with closed dies of the three different types. Figures 8-11 show how the material was deformed and the extent of rising into the upper die during different stages of one blow. Fig. 12 gives

an example of a principal curve for the pressure course. This curve can be divided into three main parts. First, the upsetting of the blank until it reaches the wall of the die and closes the flash gap. Second, the pressure is rising rapidly and the material is filling out the die. At the same time a certain amount of metal is extruded through the flash gap. Third, the excess material is upset until the dies are totally closed or all energy is consumed. The internal pressure in the material during the second and third periods is found to be dependent mainly on the height of the flash gap as is shown in fig. 13.

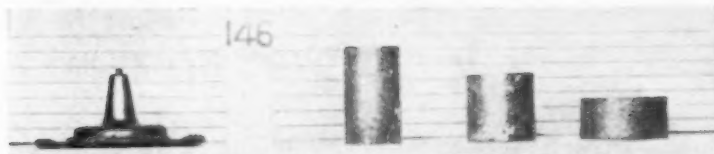
In Tables 2 and 3 are shown results of some experiments to determine the influence of size of test piece and height of blow, respectively. For



9 Sections showing the flow of the metal at the four stages shown in 8. The figures show the height of flash gap and component and also the maximum pressure obtained

11 Sections showing the flow of the metal at four of the five stages shown in 10. The figures indicate height of flash gap and component and also the maximum pressure obtained

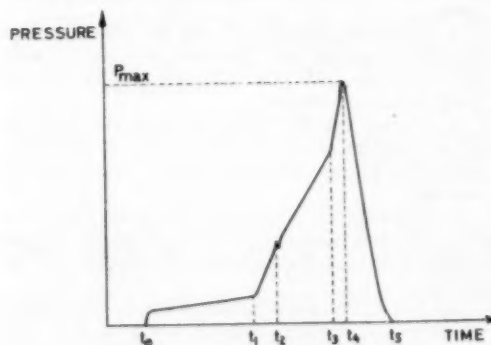




14 View of a component forged in tool B and three blanks of different shape but with the same volume (weight 552 g). The cavity was filled out completely in all three cases

a given die impression there is a minimum volume of the blank below which the metal will not fill out the cavity. Volumes exceeding the minimum will require more energy and a higher stress to produce a full component.

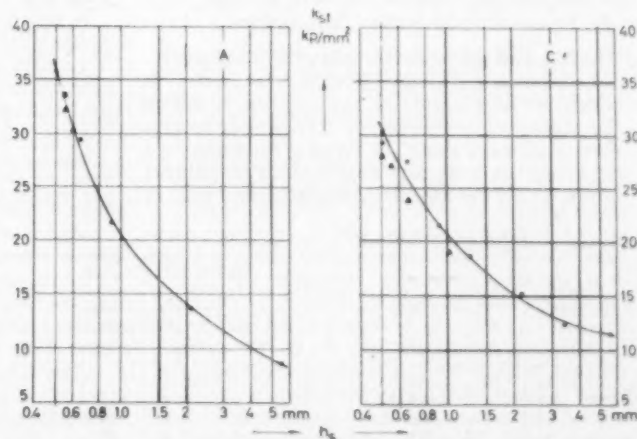
In a similar way a minimum height for a single blow can be determined for each size of the blank, below which it will be impossible to attain the amount of stress and energy required to force the metal to fill out the cavity completely. Using a height greater than the necessary minimum will not affect the forgings, but will increase the energy consumption as well as the forging pressure and will cause increased wear on the tools. Fig. 14



12 ABOVE Principal pressure curve for a complete blow with closed dies. At  $t_0$  the upper die hits the blank, at  $t_1$  the metal reaches the flash gap and closes it, at  $t_2$  the extrusion of metal through the gap begins, at  $t_3$  the cavity is completely filled with metal and at  $t_4$  the movement is stopped (the dies being closed or the energy being consumed)

13 RIGHT Relationship between maximum stress in the metal and height of flash gap ( $h_2$ ) for two experimental dies (A and C)

- Tests with the dies totally closed
- ▲ Tests with the dies not closed (flash too thick)



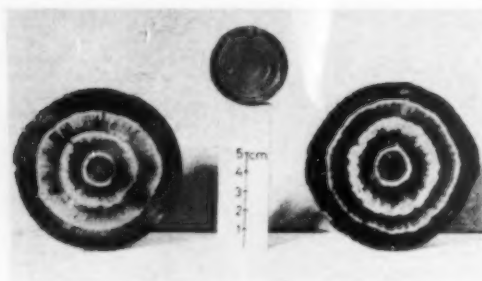
Blank size (mm.)	φ33 × 57	φ40 × 40	φ50 × 25
Blow height necessary (mm.)	1,140	1,025	730
Velocity of tup (m./s.)	4.6	4.4	3.7
Kinetic energy of tup (kpm.)	500	450	320
Maximum pressure (Mp.)	56.3	55.0	54.2

TABLE 2 Determination of the minimum blank volume (weight) for a given die impression

Test No.	Weight of blank, g.	Blow height, mm.	Over-thickness of component, mm.	Maximum pressure	Filling of central cavity
P 200	700	950	0.60	67	Not full
P 198	667	950	0.10	81	Full
P 181	660	950	0.10	86	Full
P 199	649	950	0.05	70	Not full
P 184	649	1,000	0.00	74	Full

TABLE 3 Determining the minimum blow height for a given die impression and blank size

Test No.	Blow height, mm.	Over-thickness of component, mm.	Maximum pressure, tons
P 185	1,100	0	78.9
P 184	1,000	0	73.6
P 199	950	0.05	70.0
P 201	900	0.05	67.3
P 202	800	0.10	63.5



15 Effect of lubrication on the metal flow by upsetting of cylinders marked with concentric rings on the end surfaces. a View of the test pieces before and after the blow, lubricated piece to the right

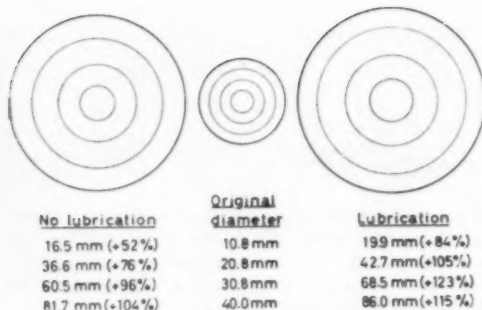
shows how the shape of the blank influences the energy required for a certain component.

The main factor forcing the metal to fill out the die is not the total falling energy of the tup or its velocity, but is found to be the pressure obtained in the metal. This pressure can be controlled by altering the dimensions of the die.

**Effect of lubrication.** During both series of tests the effect of lubrication has been studied. Fig. 15 shows how the end area of a test cylinder with concentric rings is increased by upsetting with and without lubrication. Table 4 shows how less pressure is needed with lubrication and how the test piece is deformed to a greater extent. These experiments indicate that the metal glides along the tool surface causing friction. The friction consumes part of the energy. With lubrication the loss of energy through friction is less, and more is thus available for the work of deforming. As a result, lower stress is required for the deformation and the optimum height of an upset blank will be less with lubrication than without.

#### Scaling and decarburization of heated steel

Another field of rather more general interest in which we have started an investigation is that of the scaling of heated steel. The aim is to gain more knowledge about the forming conditions and the properties of the scale so as to study possibilities of preventing the formation of unnecessary scale or



b Increase in diameter of the marking rings. The colour in the marking rings may have caused a certain lubrication effect by 'no lubrication'-test

obtaining the most harmless scale when scaling cannot be avoided. So far only some preliminary tests have been made and the specimens examined at the Institute for metals in Stockholm by Mr. Sten Modin. However, some most encouraging results have been obtained in these introductory tests:

1. A molten phase of silicates has been found in the microstructure as a thin layer between the steel and the inner oxide phase, wüstite, in plain carbon steel containing silicon.

2. During the first stage of oxidation, with an air atmosphere an excess temperature of 60°–80° C above the furnace temperature has been measured optically.

3. Forming of blisters in the scale has been observed and is thought to be a result of CO gas pressure and a certain amount of plasticity in the oxide.

4. The molten silicate-phase seems to be enriched between the blisters, causing heavy erosion and great adherence of the scale on such spots.

A first report of this work will be published in *Jernkontorets Annaler* in the near future.\* To make it possible to intensify this investigation we have received financial support from a government fund for technical research.

\*Since published (*Jernkontorets Annaler*, 1960, 144, (11), 813). An English version of this article is being prepared and will shortly appear in METAL TREATMENT

TABLE 4 Effect of lubrication on upsetting cylinders

Size of the blank, mm.	$\frac{d}{h}$	Weight, g.	$V, m/s$	Without lubrication					With lubrication				
				Test No.	Time ms.	Final height, mm.	Max. pressure, tons	$k_{st}$ kp./mm. <sup>2</sup>	Test No.	Time, ms.	Final height, mm.	Max. pressure, tons	$k_{st}$ kp./mm. <sup>2</sup>
φ50 × 50	1.0	1,220	4	P 38	11.5	18.8	13.3	6.8	P 52	12.6	16.8	9.9	5.0
φ50 × 30	1.6	694	4	P 30	8.0	8.4	22.4	11.4	P 48	8.3	7.7	17.7	9.0
φ40 × 40	1.0	558	4	P 39	11.0	8.0	22.6	11.5	P 51	11.6	7.1	18.8	9.6
φ33 × 33	1.0	321	4	P 40	9.0	3.8	45	23	P 50	9.1	2.8	32.1	16.4

## Precision forging of steel shafts

*'Modern trends in the manipulation of metals' was the theme of a conference held at Brighton last October by the Institution of Production Engineers. The present article is the third in the series on precision forging to be published in METAL TREATMENT. It is based on the talk given by Mr. Robert Speck, A.M.I.Prod.E., Robert Speck (Machine Tools) Ltd., also a director of Acton Bolt Ltd.*

PRODUCTION engineers must seek constantly to save costs in manufacture through reducing material consumption and simplifying metal-working procedure by keeping removal of metal by machine processes to the minimum. Today, it is probably true to say that, by securing precision forged steel components, more real cost saving is possible than by any other single means.

Apart from achieving the most economical use of costly steel alloys, it has become more than ever necessary now that forgings should be consistently accurate dimensionally, free from flashline, and conform regularly to a pattern. Only in this way can proper functioning be assured of automatic machine tools equipped with mechanical self-loading and unloading aids, frequently linked one with another by workpiece transfer devices.

To these ends great strides forward have been made during the past ten years by designers of forging plant in producing profiled parts of both simple and complicated forms—bevel toothed and internal toothed gears combined, with adjacent forms and projections included, for example, which hitherto would have required manufacture as individual items to be machined separately for assembly together at later stages. A wide variety of such forgings can now be produced quickly to accurate dimensions, and consistently to a weight within 2% or 3% of the finished machined article, so achieving material economies of 30% and even 50% by weight alone, in comparison with normal stampings.

To this must be added the considerable saving of costly man and machine hours; savings accruing from reductions in transportation charges through reduced weights and bulks; much lower consumption of expensive cutting tool alloys in machining; smaller horse power consumption in machining; far less wear and tear on machine tools, much reduced swarf production and handling costs; and, by no means the least factor, greatly improved handling during machine loading, inter-machine transfer, and inspection.

### Precision forging multiple-diameter shafts

This paper is concerned particularly with plant for producing multiple-diameter shaft components by precision forging methods, which can be done now in floor-to-floor times usually considerably shorter than those required for the rough machining only of conventional forgings. Rough machining can be practically eliminated very often by these new processes, leaving finishing to be done by light turning, milling and grinding operations.

Truly round and straight multiple-diameter shafts, parallel or tapered, and at times incorporating special forms, are produced from hot steel billets in floor-to-floor times shorter by far than most other methods, including turning from the bar, and with dimensional accuracies of the order of plus or minus 0.010 in. diametrically and between shoulder faces. Moreover, these forgings have no flashline.

Foremost in this field is the type of forging machine incorporating multiple hammers of simple pattern and profile arranged to reciprocate at high speed, while a billet of heated steel is passed automatically between them to be swaged down to a pre-set pattern of diameters and lengths. Contrary to normal upsetting methods, this particular process of precision forging reduces material from large to smaller cross-sectional areas, at the same time stretching it longitudinally.

### Advantages of the system

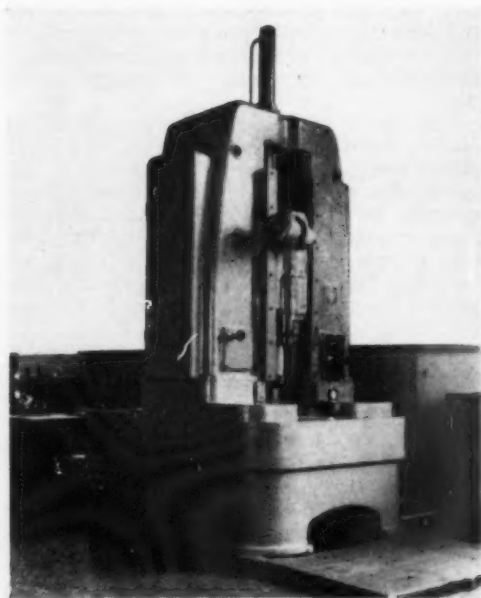
1. As the required total reductions of size in a piece are achieved with a series of swaging operations carried out at high speed by a method dividing the forging forces between a multiplicity of small blows, the designers have been able to build machines comparatively small in bulk and weight in relation to the size of components they can process. Much less shop floor space is needed for this type of plant in comparison with other methods.

2. The finished form of the piece is not governed only by the shape of the dies, as is usual, but also through the medium of adjustable stops and, in

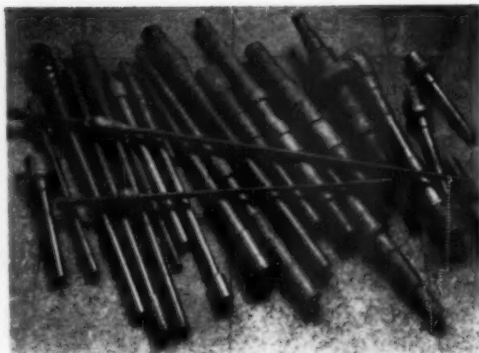
certain instances, templates. In this way it is possible to produce forgings of a wide range of diameters and lengths using only one set of simple and inexpensive tools. The change over from one size of workpiece to another is simple, the procedure being similar to that of setting up an automatic chucking or turret lathe. Small batch quantities can often be produced as forgings which could not possibly be justified by the costs of die manufacture necessary for other forging methods to be used.

3. Dimensional accuracies of finished forgings together with the speeds of production obtained are outstanding. Tolerances of  $\pm 0.010$  in. are guaranteed for diameters up to  $2\frac{1}{2}$  in. and straightness to within  $\frac{1}{16}$  in. for lengths up to, say, 24 in., while for diameters and lengths larger and longer, dimensional allowances are relatively very little different. The amount of material to be left on any diameter at any position on the workpiece can be controlled exactly.

At the same time, surface finish appearance can be smooth enough to permit machining to be dispensed with altogether where it is not a bearing surface. The processing of automobile axle transmission shafts in particular has been much simplified.



1 Example of a precision hammer forging machine of vertical construction



2 Examples of precision hammer forged shafts

### Operating details

The process was developed at first for round material sections only but machines are being built now for handling square, rectangular and polygon sections with equal facility. For certain ranges of work, machines of vertical construction are the most satisfactory, while for heavy section materials horizontal construction is favoured. Whichever is employed, however, the general construction and principles of operation are similar, and either style of machine can be installed without provision of elaborate foundations of the depth and solidity demanded by conventional stamping machines. In fact, plant of this nature can be regarded as precision machine tool equipment for installation alongside lathes and milling machines, upon which it will have no adverse effect through vibration, noise or any other undesirable aspect.

As mentioned earlier, with this style of machine a pre-heated billet is loaded into and held by a chuck during processing. The chuck is air-operated and motor-driven to rotate the billet while feeding it automatically through the reciprocating forging hammers arranged symmetrically around the work. The construction of the chuck is such that all forces exerted upon it are absorbed by spring cushions and special rubber pads to eliminate vibration. Protection for hammers against accidental working also is provided through special replaceable shear plates incorporated in the driving mechanism assemblies, one for each hammer.

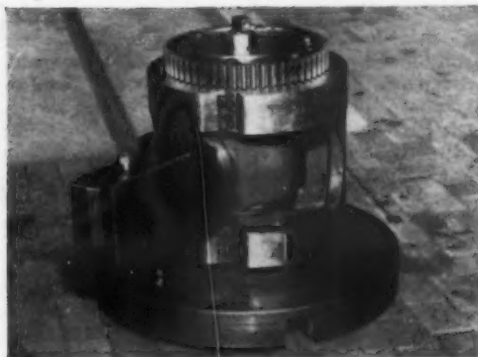
The principal part of the machine is the forging box, containing reciprocating shafts driven from fast-running eccentric bushes and transmitting their movements through guided connecting rods directly to their respective forging hammers.

The reciprocating shafts, three or four according to the type of machine employed, are arranged symmetrically about the work and their movements





3 View showing finish precision forged shaft gripped by chuck and being withdrawn vertically from the hammers



4 Precision hammer block and eccentric-drive head

are synchronized so that the forging actions take place at all points on the same axis at the same time.

In this manner the forging blows are brought into equilibrium and the machine foundations not affected by transmitted vibrations. The forging box is heavy and rigid in construction to withstand the continuous hammering, and the guides of the hammer connecting rods are specially designed to avoid separate bearings between the eccentric rods and the ends carrying the hammers. The number of main bearings has thereby been kept to the minimum, the whole construction simplified, and speeds of operation so increased as to be far in excess of those possible by alternative methods of equal working capacity.

Shafts are pressure-lubricated, guides water-cooled and hammers air-cooled to extract as effectively as possible the heat absorbed from billets. It is interesting to note in this respect that temperatures for forging by these methods average about 100° less than those necessary for other methods, and that maintenance of a set temperature is not critical. This greatly assists in keeping down furnace operating costs and contributes directly to prevention of scale formation, which is a most important factor affecting forging tool life and the good surface finishes obtained by these methods.

#### Automatic controls

The system of cycle control used is primarily hydraulic. It is fully automatic in operation and, once a forging cycle has been started, it continues until the work is completed. Except for starting the machine, an operator's only responsibilities are the loading and unloading of billets and finished pieces for each cycle.

The automatic controls provide for the following functions: (a) radial setting of hammers to accord

with diameters to be forged; (b) axial traverse of work to accord with lengths required between shoulders of the respective diameters; (c) changes of work traverse speeds and forging hammer in feeds in relation to step reductions made; and (d) withdrawal of work from the hammers and stopping of the machine ready for unloading.

The various diameters and lengths are set by means of stops on horizontal and vertical cycle control drums within the main frame of the machine, the hydraulic control system being arranged in such a manner that diameters and corresponding lengths between shoulders are forged successively in a single cycle.

Through adjustable throttle valves controlled from trips on these drums, forging speeds are chosen automatically to be selected in accordance with surface-finish qualities required for the different diameters.

Tapered diameters can be included in the same cycle as parallel diameters. This is achieved through the medium of a simple template mounted within the body of the machine and having an angle of taper corresponding with that of the work. In operation this template takes over functions of the normal stops and allows the forging hammers to feed in progressively as a billet passes through them. At the end of the taper section normal working is resumed as for parallel diameters, and without attention in any way from the machine minder. The maximum included angle of taper possible is about 20 deg.

#### Further possibilities

Further possibilities are for direct in-forming of profiles, round in section although not necessarily symmetrical in form—such parts as ball steering pins, valve stems, rocker operating rods, short



multi-diameter shafts and like pieces. These can be made in 'sticks' or multiples and left as one shaft for subsequent turning, before heat treatment. Afterwards they can be separated by sawing off or shearing. Forging tools for such pieces are restricted generally to the particular parts for which they have been made and are not suitable usually for any other pieces.

Actual forging times achieved by these types of machines depend upon work traverse speeds, in feeding to depth times for the hammers and machine idle movement times, these in turn being decided chiefly from the nature of the surface finishes required.

Naturally times can be varied considerably, therefore, but, as a general guide, one would expect for shaft of diameter between 1 and 4 in., and length from 6-40 in., that times would range approximately between 20 sec. and 120-180 sec. These would be floor-to-floor times for an average six- or seven-diameter shaft.

Sequence of operational working and the various feeds to be used will be decided by the production layout department when drawing up working schemes. This procedure is simple and akin to preparation of any tooling layout, and ensures the machine will work to best advantage and under controlled conditions at all times.

Normally any number of diameters up to about seven can be produced in a single and uninterrupted cycle, but when the two shaft ends are smaller than the centre or one other diameter, it will be necessary then for the cycle to be interrupted at a suitable point, the part reversed and the cycle restarted to be completed. On the other hand, if the two ends are symmetrical from the centre, then 14 or so diameters could be completed by this reversal procedure.

An alternative method is to use two distinct settings, changing over for the second end upon completion of the batch run on the first end. Which is most economical will be determined usually by the quantities involved and whether or not a re-heat is necessary, this being decided by the volume of the piece and cycle time for the first operation. In the majority of cases pieces can be completed in a single heat. The choice of methods will depend also upon whether more than one machine is available.

On certain types of these machines introduced recently, electronic systems of cycle control setting are incorporated to simplify procedure and to enable dimensional readings to be taken directly from drawings. It is possible in some cases also to profile forge through the medium of a manually operated tracer head, copying directly from a drawing mounted on a special control desk adjacent to the machine. With the horizontal construction one

#### Research and development in the machine tool industry

In a recent announcement, the Machine Tool Trades Association and the Department of Scientific and Industrial Research state the main conclusions and recommendations of the DSIR confidential report on 'The research and development requirements of the British machine tool industry,' and the measures which have been agreed between the Government and the industry to implement the recommendations.

The main conclusions are that the industry would benefit from employing more specially qualified designers and engineers and that a substantial increase in training facilities would make a most important contribution to the technological development of the industry. The recommendations cover measures to increase concurrently facilities for education and research in the field of machine tool technology.

The Machine Tool Trades Association has already announced the formation of a Machine Tool Industry Research Association and the DSIR is increasing the research effort in the machine tool field at the National Engineering Laboratory. Both the industry and the DSIR are contributing to the development of schools of higher training and research at two universities and two Colleges of Advanced Technology. In addition, the DSIR is considering proposals for the development of advanced machine tool designs under contract.

#### G.K.N. Group Research Laboratory

The G.K.N. Group Research Laboratory (the central research and development organization for the Guest Keen and Nettlefolds group of companies) has just installed a scanning electron probe X-ray microanalyser, manufactured by the Cambridge Instrument Co.

This is only the fourth commercial instrument of this type to be installed in this country. Other installations are at the Atomic Weapons Research Establishment, Aldermaston, Sheffield University, and the Thornton Research Centre.

The G.K.N. installation follows the recent acquisition of a Vickers EM6 electron microscope. The equipment will provide powerful support for a programme of basic research designed to improve, and to widen the range of properties available, in steel and steel products, manufactured in the Group. One such project being carried out under a Ministry of Aviation contract, concerns the development of a high-tensile weldable steel for rocket casings. Other projects include an investigation into the sources of non-metallic inclusions, and a study of segregation during the solidification of steel, and the means by which it may be overcome.

can have work holding chucks to both right and left of the central forging box, each side being equipped with mechanical and automatic work loading and unloading devices. With such machines it is possible theoretically for production to continue without interruption throughout the working day.

To conclude, these methods of precision forging are foremost in the latest techniques of modern trends in manipulation of metals. They ensure the minimum of metal being consumed for manufacture of a given article, demanding the minimum of final processing by machining.

# Electron microscope investigation of S.A.P. structures

H. HUG and DR. H. BICHSEL

*Earlier work on S.A.P. structure investigation with the electron microscope is discussed in relation to the available techniques. The authors then describe their own work in this field, first reported in 'Metall,' January, 1961. The authors are both members of the Research Institute of the Aluminium-Industrie- Aktiengesellschaft, at Neuhausen am Rheinfall, Switzerland*

FOR THE INVESTIGATION of the dispersion-strengthened aluminium alloys, known under the designation S.A.P., which is the protected trade name of the AIAG for these high heat-resisting aluminium alloys, the optical microscope cannot be employed on account of the extremely fine distribution of the oxide phase. Direct information concerning the structure of these materials can, however, be obtained by means of the electron microscope. The so-called 'heavy' aluminium powder, which is produced under definite conditions in ball mills, and is used for the production of S.A.P., consists, as is evident from polished cross-sections viewed in the optical microscope, of individual, very fine, lamellae welded together and interspersed with oxide. Fig. 1 shows this structure in an early stage of the grinding process. Here the individual lamellae, which are folded together, are still very readily visible.

During grinding, new metallic surfaces are continuously exposed on the powder particles, and the particles become enveloped in oxide which penetrates into their interior during the course of the grinding process. The production of the semi-finished product follows as a result of cold compacting of the powder, sintering and subsequent extrusion.

For metals research by means of the electron microscope mainly two methods are available, the replica technique and transmission through ultra-thin metal foils. By the first method a replica is taken of the surface, using a film of collodion, carbon or oxide. Preparation of the specimens, by mechanical or electrolytic polishing and etching, may considerably affect the surface relief, so that account must be taken of the preceding treatment during the assessment of the resultant replicas.

The first electron micrographs of S.A.P. were published by E. Gregory and N. J. Grant.<sup>1</sup> The

specimens were polished by these authors in a perchloric acid-acetic anhydride bath and, without subsequent etching, a collodion film replica was taken (fig. 2). The white areas represent oxide particles. Their density increases with the oxide content of the initial material. As experience shows, the collodion replica method is too coarse for the reproduction of the shape of the fine oxide particles. On this account, the replicas obtained by Gregory and Grant are still relatively indistinct and, in the opinion of the authors, afford only rough indications. An investigation recently carried out by N. Hansen, E. Adolph and J. Christensen,<sup>2</sup> during which a combined collodion-carbon replica technique was used, produced similar microstructures. On these micrographs we can nevertheless clearly distinguish, by the distribution of the oxides, whether the material is S.A.P.-865, -895 or -930, containing 14, 11 and 7% oxide respectively.

The structure of S.A.P. was thoroughly investigated by F. V. Lenel, G. S. Ansell and E. C. Nelson,<sup>3</sup> in whose opinion electrolytic polishing is entirely unsuitable for preparation of the specimens, since it produces its own background structure. The metal specimens were exclusively polished by mechanical methods with great care and etched in 0.25% hydrofluoric acid in a mixture of water and alcohol. The replica was produced by means of a film of formvar, reinforced with nitrocellulose, which was vaporized with carbon after stripping. This was followed by shadowing with chromium at an angle of 45 deg. As opposed to the method used by Gregory and Grant, the replica film is not mechanically deformed during stripping.

Finally, carbon films are more stable than collodion films, for the latter shrink easily during electron radiation. From the electron micrographs of these authors the platelet structure of the oxide

is clearly evident. The oxide particles are not distributed in a random orientation, but ordered in groups of parallel platelets, between which is the oxide-free metal.

Conclusive modelling experiments, which afford an insight into the oxide distribution after sintering and mechanical working, were carried out by J. Hérenghuel and J. Boghen<sup>4</sup> and also by H. G. Cole.<sup>5</sup> As sintered bodies the former authors employed laminated, anodically oxidized sheets (sheet thickness 200  $\mu$ , oxide layer thickness 4  $\mu$ ) which were packed into an aluminium can and hot rolled at 625°C. The groupings of the oxides which were found after cold rolling made it possible to draw certain conclusions concerning the mechanism of deformation and the structure of S.A.P. At high degrees of reduction (60–80%) the oxide layers along the rolling direction had already been broken up into individual pieces, yet the sandwich structure of the initial structure was still readily recognizable. With the increase in the degree of deformation the linear orientation of the oxide fragments was increasingly wiped out and, at the same time, larger oxide-free zones were formed. For the most part the oxide fragments remained preserved as a double layer.

Similar results were obtained by Cole,<sup>5</sup> who compressed at 500°C. a pile of anodically oxidized sheet discs, placed one on top of the other. Except for the areas where no flow of the metal occurred, the oxide layers were for the most part broken up. Even in the highly deformed areas the two neighbouring oxide layers were almost always left in close contact as a double layer. Both models permit the assumption that during the manufacture of S.A.P. semi-finished products the oxide films likewise break up and are embedded in the metal matrix.

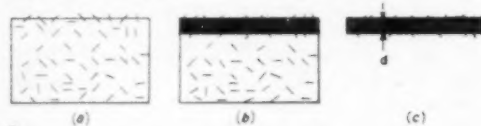
### Experimental section

During systematic testing of electron microscope replica methods it was shown that the oxide replica method is particularly suitable for S.A.P.

The mechanically polished specimen, connected as the anode, is electrolytically polished for 40–60 sec. The temperature of the chromic acid-sulphuric acid electrolyte is 65–75°C., and the bath voltage 10–12 volts. The composition of the electrolyte is: 408 cm.<sup>3</sup> H<sub>3</sub>PO<sub>4</sub> ( $d = 1.7$ ) + 78 g. CrO<sub>3</sub> + 67 cm.<sup>3</sup> conc. H<sub>2</sub>SO<sub>4</sub> + 20 cm.<sup>3</sup> distilled water. By this method the polish of the surface is preserved, as opposed to the use of a perchloric acid-alcohol electrolyte, in which S.A.P. specimens are covered with a greyish-black film. After electrolytic polishing, the specimen is anodically oxidized in an electrolyte containing 60 g. Na<sub>2</sub>HPO<sub>4</sub> + 2 cm.<sup>3</sup> conc. H<sub>2</sub>SO<sub>4</sub> per litre H<sub>2</sub>O. The textureless oxide layer, which shows a thickness of about 300 Å at

a bath voltage of 20 volts, is divided up by scratch marks into small squares (length of sides 2–3 mm.), and is loosened by immersing the polished specimen into a saturated mercuric chloride solution. Release of the oxide layer is often somewhat laborious with S.A.P., and it is therefore recommended that the mercuric chloride solution should be slightly warmed. After cleaning in dilute hydrochloric acid and washing three times, the oxide films are fixed on the carrier grids.

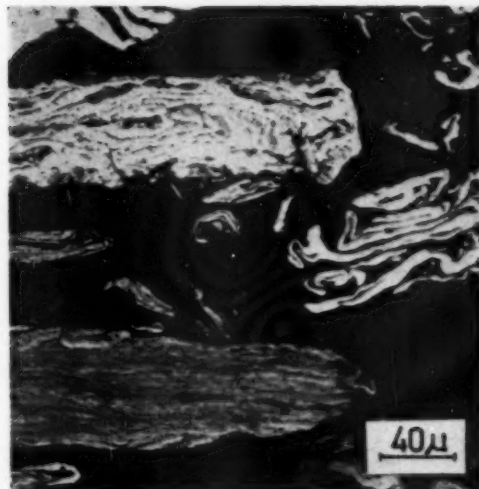
Before going into details of the electron micrographs, for the sake of better understanding the replica method will be considered somewhat more thoroughly. The individual stages of the preparation of the specimens are represented diagrammatically in figs. 3a–c. Fig. 3a shows the electrolytically polished specimen. On the surface there are



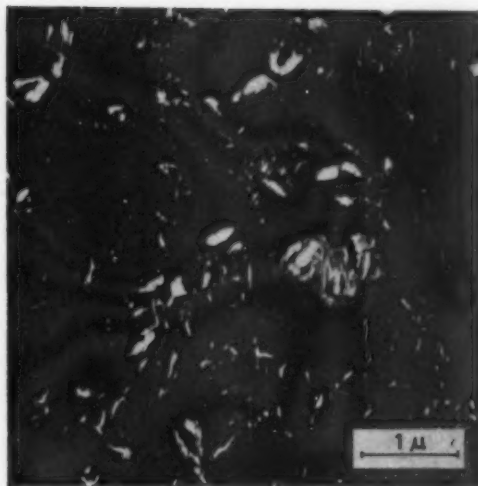
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oxide particles, which are still securely anchored in the metallic matrix. During anodic oxidation the oxide flakes of the S.A.P. are incorporated in the oxide film with an orientation corresponding to their existing position (fig. 3b). In this way we obtain an extraction replica which, as fig. 3c shows, reproduced the oxide flakes in true shape and orientation. The oxide replica technique makes possible a considerably better reproduction of the S.A.P. structure than the collodion-formvar and carbon replica methods mentioned above.

Fig. 4 shows an example of this replica technique. The initial material employed was S.A.P.-930 round bar, which was ground at right-angles to the direction of extrusion. The dark, rod-shaped particles are oxide flakes, which have arranged themselves parallel to the direction of extrusion, and in the cross-section display their side view. In this position the thickness of the platelets can be measured. For the thinnest rod structures, which correspond to flakes lying at right angles, or at a high angle to the surface of the specimen, this amounts to 150–250 Å. On the assumption that, in accordance with the modelling experiments of Hérenghuel and Boghen<sup>4</sup> and of Cole,<sup>5</sup> it is a matter of double layers, then the thickness of the individual oxide platelets amounts to 75–120 Å. From closer observation the two layers are recognizable on many of the rod structures (fig. 4). The measured values are in good agreement with the thickness data for natural oxide layers on aluminium surfaces of W. H. J. Vernon<sup>6</sup> and A. U. Obrist,<sup>7</sup> which vary between 80 and 150 Å according to the method of determination.



1 Structure of S.A.P. powder particles (optical microscope) etched in Dix solution



2 Structure of S.A.P. 865 from a micrograph of E. Gregory and N. J. Grant (collodion replica)

Flakes which lie in the plane of the specimen appear transparent in the electron micrograph. Apart from the oxide flakes with irregular and jagged outlines, occasionally particles are also observed with straight edges and a hexagonal shape. These must, in fact, have originated in the transformation of the oxide phase during sintering. In addition, larger agglomerations of oxide particles, visible as dark masses, may also be recognized. There is clearly a certain similarity with fig. 2.

As already mentioned, the oxide flakes show a tendency to orient themselves during the hot and cold working of the material. In thin sheets they are arranged parallel to the surface of the sheet, while in extruded products the majority of the oxide flakes are oriented along the flow lines (fig. 5).

As a section of fig. 5 at a higher magnification (fig. 6) shows, not only the coarse but also the fine, flake-like oxide particles are arranged along the direction of extrusion.

In fig. 7 we see the structure revealed by transmission of an S.A.P. foil, thinned down in a chromic acid-sulphuric acid polishing bath to a thickness of  $0.1 \mu$ , in accordance with the 'window technique' of H. M. Tomlinson.<sup>8</sup> The illustration shows, in addition to the shape of the oxide flakes lying in the plane of the micrograph, defined areas of the order of  $0.5 \mu$  in size. This value corresponds roughly to the thickness of the individual lamellae of a powder particle. Whether in the areas indicated residues of the original powder structure are present, or whether sub-grains have formed in zones poor in oxide cannot yet be determined with

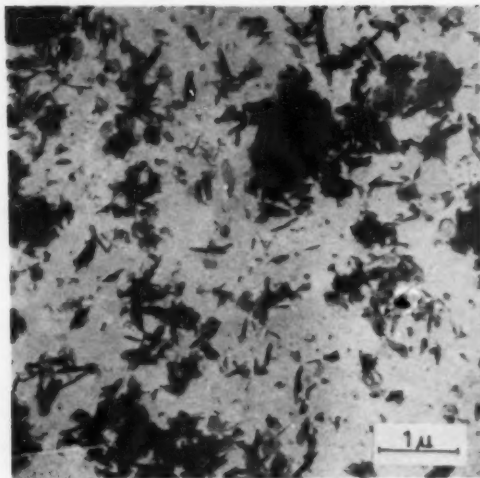
certainty; to conclude from the shape of these areas the latter alternative is the more probable. In fig. 7, in addition isolated dislocations and dislocation arrangements are also recognizable, which will not be gone into in this context. It is known that the special properties of S.A.P. are today generally explained on the basis of the interactions between the dislocations and the oxide particles.

#### Investigations on oxide isolated from S.A.P. powder, sintered S.A.P. and extruded S.A.P.

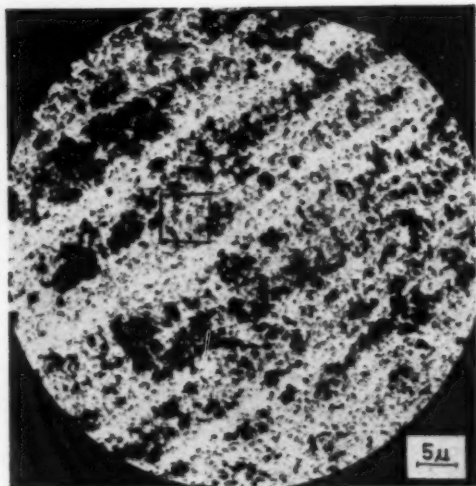
The shape of the finely dispersed oxide particles distributed in S.A.P. semi-finished product is apparent from figs. 4-7. Further experiments served to isolate the oxide from S.A.P. material at various stages of its manufacture. A suitable method of separation, causing the least possible damage, is afforded by dissolution of the metallic component in bromo-methanol.

Powder (5 g.) or machined chips are introduced a little at a time with cooling into  $100 \text{ cm}^3$  of a 15% by volume solution of bromine in anhydrous methanol. The reaction proceeds most completely with extruded material, and to the least extent with powder, since the particles are evidently very closely enveloped by oxide sheaths. The oxide is so finely dispersed, that it cannot be isolated by filtration; on the other hand, it can be separated by centrifuging (5 min. at 3,500 r.p.m.). By means of repeated suspension of the oxide, which is grey in appearance, in methanol and subsequent centrifuging the specimen is cleaned. A drop of





4 Transverse cross-section through a 15-mm. round bar of S.A.P. 930 (oxide replica)



5 Longitudinal cross-section through a 15-mm. round bar of S.A.P. 930 (oxide replica)

this suspension is placed on a supporting carbon film, which is produced by vaporization on to a glass plate, and can later be investigated in the electron microscope.

Fig. 8 shows the isolated oxide skin of a powder particle. The dark areas are metal residues, which were not completely removed by the bromomethanol. One can clearly recognize extinction contours and dislocations, which are typical of metal irradiated in the electron microscope. The oxide skin consists of several layers, whereby the metal is, so to speak, trapped within the pockets of oxide skins. The thickness of these metal residues, roughly assessed from their electron penetrability, amounts to 0.2-0.5  $\mu$ . The parallel lines correspond to the inherent structure of the supporting film, and have nothing to do with the specimen.

The oxide isolated from S.A.P. bolts sintered at 600°C. has a different appearance. As fig. 9 shows, no cohesive skins are present any longer, but here the oxide has broken down into flake-like or lamellar particles. As was to be expected, they lie parallel to the supporting film. Comparison with the transmission micrograph of the thinned S.A.P. foil (fig. 7) shows outstanding agreement in relation to the shape of the oxide flakes. In the course of the hot and cold working the oxide particles are broken up. The isolated oxide from extruded S.A.P. semi-finished products shows in essence the same appearance as fig. 9, but at the same time the size of the flakes is estimated to be one and a half times smaller.

#### X-ray investigation

From the isolated oxide specimens Debye-Scherrer patterns were prepared, from which it was possible to establish the following:

The oxide specimen produced from S.A.P. powder shows no aluminium oxide lines. Only aluminium lines were found, which originated from the trapped metal residues (see fig. 8). The oxide in the ground powder is amorphous under X-ray examination.

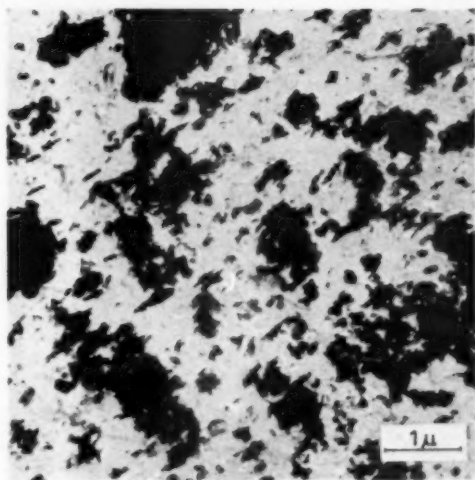
The isolated oxides from sintered and extruded bolts both show the pattern of  $\gamma$ -alumina, and the width of the line permits the conclusion that the particles are very small in size. That the aluminium oxide in S.A.P. exists as  $\gamma$ -alumina has already been mentioned by R. Irrmann.<sup>9</sup>

#### Discussion

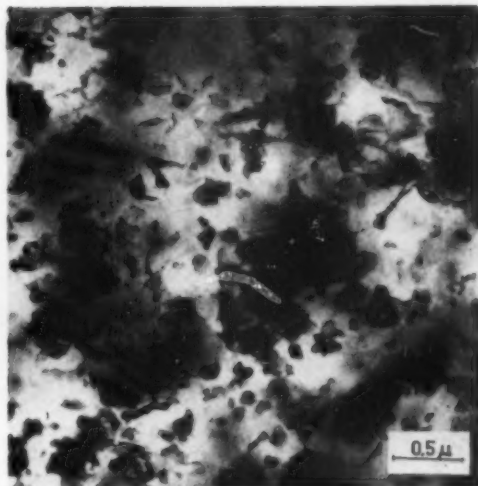
The electron microscope investigation of the structure of S.A.P. material at various stages in the production of the semi-finished product, in particular also of the isolated oxide, affords a contribution to the understanding of the process of sintering aluminium powder.

An interesting and conclusive work concerning dilatometric and resistance measurements on aluminium powder compacts by N. A. McKinnon<sup>10</sup> shows that the electrical resistance, as was to be expected, is strongly influenced by the compacting pressure. At lower pressure corresponding to low metal contact, the electrical resistance is very much higher. On the other hand, a relationship exists

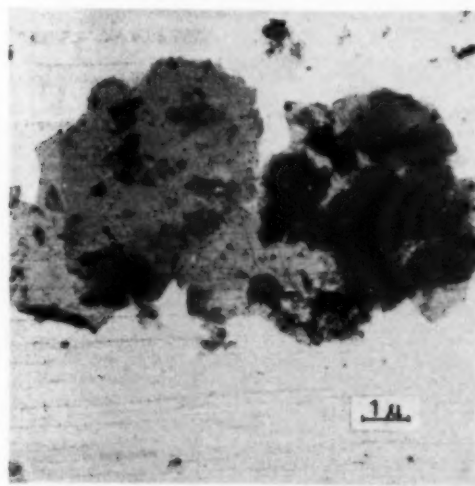




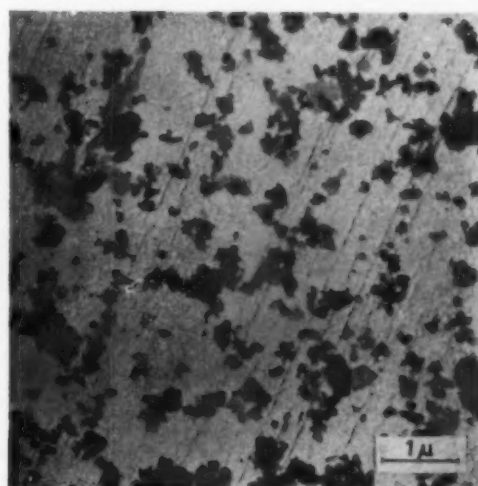
6 Longitudinal cross-section through a 15-mm. round bar of S.A.P. 930. Detail from fig. 5 (oxide replica)



7 S.A.P. 930 foil (transmission micrograph)



8 Isolated oxide sheath from S.A.P. 930 powder (dark areas are metal residues)



9 Isolated oxide from sintered S.A.P. 930 bolt

with the sintering temperature, since the electrical resistance for all compacting pressures decreases abruptly by several decimal points within a narrow temperature range between 500 and 520°C. This phenomenon is indicated by a sudden break-up of the oxide skins.

There is an interesting connection between this result and experiments which have been carried out

in the Research Institute of the AIAG in Neuhausen am Rheinfall.<sup>11</sup> During the heating of compacts from S.A.P. powder, between 525 and 550°C. a sudden rise in temperature of about 100°C. occurs, while the gas content of the sintered body changes. The drop in the gas content is accompanied by a simultaneous rise in the proportion of oxide. This behaviour, especially the rise in tem-

perature, is attributed to an oxide transformation. The amorphous oxide containing hydroxyl ions splits off water in the temperature range indicated, and the water in its turn again undergoes a strongly exothermic reaction with the aluminium with formation of  $Al_2O_3$  and hydrogen.

The electron microscope observations, from the oxide skins of the powder to the small oxide platelets in the sintered material, fit quite naturally into the results of this research. The X-ray investigations show that the transformation of the amorphous oxide film of the powder particles into the crystalline  $\gamma$ -alumina takes place during the sintering process. This transformation has already been found by G. Hass,<sup>12</sup> by means of electron diffraction carried out on oxide layers on aluminium films, produced by steaming rock salt cleavage faces. The films were oxidized in air at various temperatures. At low temperature there is formation of amorphous oxide, which is transformed at about 500°C. into crystalline  $\gamma$ -alumina. It is interesting that the transformation of an amorphous oxide layer formed by aluminium takes place at a considerably higher temperature, namely only at 680°C.<sup>13</sup> The first instance, the oxide layer in contact with the aluminium base, corresponds to the conditions in S.A.P. and it is noteworthy that the oxide transformation established by Hass takes place at approximately the same temperature as the reduction in the electrical resistance<sup>10</sup> and in the gas content.<sup>11</sup>

It is very probable that the transformation of the amorphous oxide into the  $\gamma$ -alumina takes place via the Boehmit phase. In most of the micrographs hexagonal platelets were found which correspond to the crystal habit of Boehmit. This habit, as is known from various aluminium oxide transformations, can also be retained in the  $\gamma$ -modification (pseudomorphosis).

In the present work it has been possible to prove the breakdown of the amorphous oxide skins of the powder into small, crystalline,  $\gamma$ -alumina platelets, which serves to confirm the conclusions drawn by McKinnon<sup>10</sup> on the basis of electrical measurements.

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## Soviet technicians to lecture in Britain

FOR THE FIRST TIME Russian technicians have offered to lecture to British industry. Following the recent successful visit to Moscow by a 12-man delegation representing seven leading British companies, the organizer, Mr. Greville Wynne, an industrial sales consultant, has been asked to co-ordinate arrangements for a reciprocal visit by Russian industrial representatives in April.

The party, which will be organized on the Russian side by Mr. Wynne in conjunction with the State Scientific and Technical Committee of the U.S.S.R. Council of Ministers, will spend two days in London and will then divide according to the industries represented. These industries will correspond with those of the British delegates who visited Moscow last month and the seven companies are making arrangements for the Russian technicians to tour their factories. The Russians will lecture to English technicians and engineers, on the latest developments in Soviet industry, in the various centres where their hosts have factories, i.e. Sheffield, Leeds, Co. Durham, Wolverhampton, Wallsend and London.

During their recent visit to Russia the British delegates were given the opportunity of visiting Russian factories and representatives of each company lectured to Russians working in the same industry.

Reports from both Russian and British sources speak of this mission as being most useful and successful. Several of the British companies already had established business contacts with the Soviet Union, but to others

the field was entirely fresh. Since returning, all the delegates have expressed the view that the visit will lead to increased trade with Russia.

In response to further invitations from the Soviet authorities, another delegation from British industry will visit Russia in May. Mr. Greville Wynne, who will again handle the organization, is already contacting companies who may be interested. The Russians have indicated a strong interest in certain other fields, from which it is hoped suitable representation will be forthcoming. These include telecommunications and electronic equipment, all kinds of metal treatments, and welding techniques.

## American motor industry seeks European inventions

Three major American manufacturers of automobile parts have started an active search in Europe for technical developments for which they can obtain the American licence rights. They are currently manufacturing some parts by the French Ugine-Sejournet hot-extrusion process and other parts by a German cold-extrusion process.

International Research Consultants Inc., of Geneva, Switzerland, announces that on behalf of American Metal Products Company, Kelsey-Hayes Company, and the Sparton Corporation they are currently looking for patented products and processes of European origin. The three companies have total annual sales of more than \$265,000,000 and are three of the most important American automobile part manufacturers.

*A symposium on heat treatment and other processing of stainless steels was sponsored by the Industrial Heating Equipment Association in Philadelphia, U.S.A., during the recent National Metal Congress and Exposition. The two articles given here are based on contributions to the symposium*

## Heat processing stainless steels

### *Heat treating and sintering in an atmosphere*

B. A. RUEDIGER, *Industrial Heating Dept., G.E.C., Shelbyville, Ind.*

TODAY, THROUGH THE USE of the proper atmosphere, stainless steels can be annealed, brazed, sintered and, in some instances, fully hardened without oxidation or discoloration. Since these protective atmospheres also eliminate oxidation, there is no surface depletion of chromium and, consequently, no impairment of the materials' corrosion resistance. Processing costs are reduced (because no subsequent cleaning operations are necessary) and safety hazards and disposal problems associated with acid pickling are also eliminated.

#### **Dry atmospheres needed**

When a bright surface is required, atmospheres of hydrogen, dissociated ammonia or vacuum are necessary. To prevent oxidation, the atmosphere, whether it is hydrogen or dissociated ammonia, must be dry. Quantitatively speaking, dewpoints must be lower than the metal metal-oxide equilibria of the most active elements in the alloy. For alloys such as stainless steel, where more than one element is present, a dewpoint lower than that required for the pure metal is needed. For example, while pure chromium will not oxidize at 1,090°C. if the dewpoint is below -30°C., a chromium-nickel stainless steel such as Type 304 requires furnace dewpoints of at least -35°C. Actually, the best practice for all stainless steels is to maintain a furnace dewpoint of -40°C. or lower. Stainless steels which contain titanium or aluminum (or both) are troublesome in this respect, particularly since atmosphere inlet dewpoints lower than -70°C. are not commercially feasible. Thus it would appear that these steels

cannot be successfully bright annealed except in vacuum.

However, this is not entirely true since reactions require time. Our tests, in fact, have demonstrated that Type 321 stainless does not oxidize when rapidly processed. Further, A-286 (which contains 2% Ti) and PH 15-7 Mo (which contains 0.75-1.5% Al) showed only a very light yellow discoloration after similar heat treating. However, where soaking is required (such as in sintering or heat processing heavy sections), stainless which contains aluminum or titanium should be processed in vacuum.

#### **Carburization may be a problem**

Hydrogen is an excellent carrier gas for carbon. However, since carburization impairs the corrosion resistance of stainless steel, work fixtures and atmosphere must be free of carbonaceous impurities. Recently we demonstrated the susceptibility of stainless to carburization in pure hydrogen. By annealing Type 321 stainless for 4 h. in -50°C. dewpoint hydrogen which contained 200 p.p.m. methane and 200 p.p.m. carbon monoxide, we raised the carbon content of the stainless from 0.04-0.12%, a threefold increase.

Special care must be taken to avoid carburization when heat processing the extra-low-carbon steels such as Types 304 L and 316 L. In tests which we conducted with a high-purity hydrogen atmosphere (one containing 100 p.p.m. methane, 200 p.p.m. carbon monoxide and 20 p.p.m. carbon dioxide), we found that Type 304 L would be

susceptible to carburization at dewpoints below  $-45^{\circ}\text{C}$ . Since the material will also oxidize above  $-35^{\circ}\text{C}$ . dewpoint, processing must be done in the narrow dewpoint range of  $-35^{\circ}$  to  $-45^{\circ}\text{C}$ .

#### Dissociated ammonia may cause nitriding

Dissociated ammonia, which is 75% hydrogen and 25% nitrogen, is frequently used in place of hydrogen because of its lower cost. However, there are some problems. Stainless steels are susceptible to nitriding, so heat treaters must be sure that the raw ammonia is thoroughly dissociated. The residual ammonia content in the dissociated gas should be close to equilibrium.

Ammonia dissociators operate at temperatures appreciably lower than many annealing or sintering temperatures. Even under optimum conditions, therefore, the ingoing gas contains more residual ammonia than is wanted. As a result, it is best to pass the dissociated atmosphere through an adsorbent (such as synthetic zeolite) before introducing it into the furnace.

#### Temperatures are important

Temperatures and soaking times for treatment and sintering are not fixed. In production annealing tests, the required soak for 35-mil strip was less than 1 sec., an appreciably shorter time than is needed for usual operations. Since 1½-in.-o.d. bar stock was also fully hardened with soaks of only a few minutes, it seems that it is only necessary to assure that the correct temperature has been reached—unless, of course, massive carbides, severe segregation or grain growth are factors. The amount of prior cold work also should be taken into account, because austenitic alloys that have been severely cold worked will recrystallize more rapidly and at lower temperatures.

Sintering, which requires the diffusion of metallic atoms between adjacent particles, necessitates rather long times. High sintering temperatures are recommended, since they produce a more ductile product than lower temperatures at equivalent times.

#### Two other factors

In commercial practice, a lubricant (stearic acid, zinc stearate or lithium stearate, for example) is usually used in compacting stainless powders. Though these lubricants generally improve the green compact density and increase die life, there are drawbacks. Stearates are carbonaceous compounds which, as mentioned previously, are undesirable. Also lithium and zinc are troublesome because they condense in the cooler portions of the furnace. This makes it necessary to clean the furnace quite often. Best practice is to burn off

or volatilize these lubricants in separate equipment before sintering. Separate burn-off or volatilization also reduces cracking during sintering, because the raw compacts are stress-relieved.

Most of the austenitic stainless steels are susceptible to carbide precipitation. This phenomenon, which drastically reduces the corrosion resistance of the material, occurs when the steels are cooled slowly through or held in the  $760\text{--}480^{\circ}\text{C}$ . range. Rapid cooling is therefore recommended. With the new industrial furnaces available today, bright hardening of stainless steel is practical. In fact, section sizes with thicknesses up to 1½ in. o.d. have been fully hardened without oxidation or the slightest discoloration. Precipitated carbide, however, does not interfere with forming. Consequently, in-process anneals can be slow; rapid cooling is needed only after the final anneal to prevent this carbide precipitation.

#### Gas generating equipment

High-purity hydrogen can be purchased in bottles and tank trucks or generated (up to 99.999% purity) from ammonia or natural gas. Atmospheres produced by the dissociation of liquid ammonia in an iron or nickel catalyst bed can have a dewpoint of  $-50^{\circ}\text{C}$ . and residual ammonia contents of less than 100 p.p.m.

As discussed previously, the dewpoint in the furnace must be  $-40^{\circ}\text{C}$ . or lower to ensure bright work. To maintain such low dewpoints the ingoing gas must be appreciably dryer, preferably  $-60^{\circ}$  to  $-70^{\circ}\text{C}$ . Dissociated ammonia should have a minimum residual ammonia content to prevent the possibility of nitriding.

To remove both water and residual ammonia, regenerative dryers—the active agent is either activated alumina or molecular sieve adsorbents—are available. The latter adsorbent is preferred because it provides a lower dewpoint. For best results, the 'bleed' system of reactivation is recommended. With such equipment, outlet dewpoints of hydrogen and dissociated ammonia are about  $70^{\circ}\text{C}$ ., and residual ammonia contents will drop from 500–5 p.p.m. or less.

When large quantities of gas must be dried, a split-bed dryer is economically more advantageous. A split-bed unit has both activated alumina and molecular sieve adsorbents; the first removes the bulk of the water while final drying is accomplished by the latter.

Dryers also remove carbonaceous impurities such as methane, carbon dioxide and carbon

\*Normally, the adsorbent is reactivated by heating. In the bleed system, some atmosphere is also passed through the saturated adsorbent.



monoxide. Synthetic zeolite adsorbents, however, will pass these gases as they become saturated with water. Thus an oversized dryer is preferred if these contaminants are present.

### Furnaces are versatile

For bright heat processing, equipment is available for both batch and continuous production. Although bell, horizontal mesh belt and roller hearth furnaces can be used, the box, hump-type mesh belt and pusher are more common.

Box furnaces which are lined with a high-purity refractory (completely inert to hydrogen or dissociated ammonia) can operate to 1,760°C. High-temperature furnaces — those operating above 1,150°C.—have molybdenum resistance elements. A water jacket chamber provides uniform and rapid cooling. Although available in a variety of sizes, the most common furnaces have door openings to 24 in. wide by 8 in. high. Many such furnaces are now being used for applications such as bright annealing of turbine buckets, cutlery and other small components.

Hump-type furnaces consist of an inclined charge chamber, horizontal heating chamber and cooling chamber, and declined cooling chamber. The pieces move through the furnace on a woven alloy belt. Furnaces operating to 1,200°C. are available.

This type of furnace is easy to load and unload,

and has a high production capacity. Also, less atmosphere is used in hump-type equipment because of the 'self-sealing' effect of the lighter-than-air hydrogen in the inclined charge and declined cooling chambers.

The pusher furnace is horizontal equipment. Being available for 1,760°C. operation, heating and cooling chamber construction are similar to the box furnaces. The furnace is continuous in that work is conveyed on trays that follow one another through the furnace.

The pusher furnace is ideal for sintering since it permits the use of higher temperatures than mesh belt or other types of continuous furnaces. In general sintering practice, the work enters the furnace through a purging chamber and goes through separate volatilization, sintering and cooling sections. Finally, the cooled work is removed from the furnace through a purging chamber.

The most recent advance in bright heat processing is the vertical tower furnace, a tall, narrow unit which anneals stainless-steel strip in one downward pass. The heating chamber, rated 1,260°C., is lined with high-purity alumina and heated by molybdenum resistance elements. Jet coolers provide rapid cooling to room temperature. Dewpoints of -50°C. are held continuously with hydrogen consumption of only 1,000-2,000 cu.ft. h. A typical production furnace will anneal 6,000-8,000 lb. h. of strip 0.005-0.060 in. thick and 24 in. wide.

## Vacuum furnaces are versatile

H. W. WESTEREN, C. I. Hayes Inc., Cranston, R.I.

THE 'VACUUM ATMOSPHERE,' though a relative newcomer to heat treating, is being used in an increasing number of metallurgical applications. Among them are hardening beryllium copper, tempering high-speed steels and silver brazing non-ferrous metals—to name a few. Alloys containing aluminum, titanium, columbium or tantalum can be very successfully kept free of oxidation and absorbed gases.

Before discussing some applications, however, it may be well to describe a vacuum atmosphere. It can be defined as any environment below atmospheric pressure (760 mm. Hg). Naturally, there are always residual gases in an evacuated chamber regardless of the degree of vacuum. Further, the characteristics of the material being processed affect the degree of low pressure desired. A very

high vacuum or low pressure thus does not necessarily produce good work, the proper ratio of temperature, atmosphere and cycle time being the only assurance of successful processing.

Pressures in vacuum atmospheres are measured either in millimetres of mercury or in microns. Stainless steels are usually processed between  $\frac{1}{10}$  and 1  $\mu$  of pressure, while other work may be done at 1/1,000  $\mu$  or up to 100  $\mu$ , or at whatever degree of pressure is required for satisfactory results. The chart in Fig. 1 is a convenient way to convert the various vacuum measuring systems one into the other.

To determine the correct operating pressure and procedure during heat treating, we have to consider the oxidation characteristics of the material being processed. In other words, how do we prevent



oxides from forming, or remove those already present? Since oxides at a given temperature become unstable at different pressures, we must decide which pressure will produce the best results.

Chamber tightness is also important. If the furnace chamber is not constructed and maintained

necessary, when using vacuum, to analyse closely both the oxidation and vapour pressure characteristics of the material being heat treated, so as to determine the proper temperature cycle required to process the part. In some stainless-steel processes, for example, it is necessary to heat and cool the work rapidly at controlled rates; this can be done in available vacuum equipment with excellent results by moving the work into an adjacent cooling section.

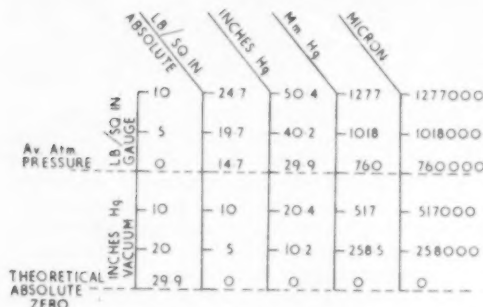
Since cycle time, outgassing and desired pressure all affect the pumping system's design, the process for the work should be properly analysed to determine the type and capacity of pumping equipment to be used.

### Typical vacuum processes

All but one of the various processes listed in Table 1 necessitate the evacuation of the chamber to a given pressure which is maintained throughout the entire heat-treatment cycle. The exception is copper brazing of stainless steel. To remove oxides from the steel and prevent copper from subliming, the chamber is first evacuated to below  $1 \mu$  pressure. Preheating to 960 C. removes oxides from the work. Then the chamber is back-filled with argon or helium to a pressure of  $10 \mu$ , the part is heated to the flow point of the copper, and the temperature is lowered under high vacuum.

When nickel brazing stainless steel, a considerable reduction in the required pumping capacity can be realized by following this procedure: Load the furnace, evacuate it down to  $100 \mu$  and preheat the parts to 700°C. Between 370° and 480 C., nickel braze resin binders become gaseous and can be evacuated. After outgassing, evacuate the chamber

continued on page 113



1 Conversion chart for atmospheric pressures

to minimize leakage, it is impossible to take full advantage of the pumping system. A poorly constructed chamber with a high leak rate will need a high pumping capacity to obtain a certain pressure. It cannot produce the results of a tight chamber (in which a lower pumping capacity answers the purpose) since infiltrating gases passing through the chamber would accelerate oxidation.

The vacuum chamber should be kept clean. Furthermore, all the parts should be cleaned and degreased before heat treatment, since any oils, greases or solvents will produce undesirable gases during heat treatment. They may also leave detrimental residues on the parts.

All materials contain gases which are released when heated to given temperatures under low pressures. Therefore, an adequate pumping system is needed to remove liberated gases and maintain the desired pressure during the heat-treating cycle. The rate of outgassing is largely dependent on the rate of heating. Even though a furnace is being operated continuously, gases are reabsorbed by the furnace components when they are exposed to atmospheric pressures. The time of this exposure will determine the amount of gas absorbed. Therefore, it is important to maintain the 'vacuum atmosphere' in the chamber whenever possible.

Another important factor is sublimation—the transformation of a material from the solid state directly to the gaseous state. This phenomenon is more frequently encountered when heat treating in low-pressure atmosphere because it occurs at lower temperatures with reduced pressures. In fact, in some stainless-steel processes, sublimation occurs at oxidizing temperatures. Therefore, it is

TABLE 1 Typical vacuum metallurgical processes

Material	Process	Pressure, $\mu$	Temp. range, C.
Beryllium copper	Hardening	$\frac{1}{10}$	345
Stainless steel ..	Hardening	$\frac{1}{10}$	345
High-speed steels	Tempering	$\frac{1}{10}$ –1	540
Ni-Span C ..	Hardening	1–100	680
Non-ferrous materials	Silver brazing	$\frac{1}{10}$	820–980
Stainless steel ..	Annealing	< 1	980
Stainless steel ..	Hardening	< 1	1,010
Stainless steel and other ferrous metals	Copper brazing	$\frac{1}{10}$ –10	1,090
Stainless steel ..	Nickel brazing	< 1	1,090–1,260
Stainless steel ..	Sintering	10–50	1,200–1,320
High-speed steels	Hardening	1	1,260
Tantalum ..	Annealing	1–100	1,425
Tungsten carbides	Sintering	50–100	1,450
Refractory metals	Platinum brazing	1	1,760

# Metallurgy in nuclear power technology

## 6. Fuel element technology

J. C. WRIGHT, B.Sc., Ph.D., A.I.M.

*The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright, Reader in Industrial Metallurgy, College of Advanced Technology, Birmingham, outlines the subject in a series of articles which are appearing monthly in this journal*

*continued from last month*

DISPERSIONS systems are normally sheathed for use as reactor fuels, frequently with the same material from which the matrix is made. One way in which the working process and the cladding process for a composite fuel element can be combined is the hot co-extrusion technique. In this process the powder compact is placed inside a can of the required canning metal and fitted with a bottom of the same material. The top of the can containing the compact is then sealed by a cone-shaped block of the canning material so that the final result looks like a stubby rocket with the powder compact as the charge. The composite billet is then heated to extrusion temperature, inserted into the preheated chamber of the press with the nose of the billet towards the die, and ejected through the die by direct extrusion. A fitting on the back of the die takes the cone nose of the billet exactly and allows simultaneous extrusion of the powder compact and the can. The cladding is very intimately bonded to the core and the section of material suitable for cutting into fuel elements can be located by a variety of non-destructive testing methods.

A similar method has been used for the cladding of normal uranium fuel bars. For instance, uranium and uranium alloys may be clad with zirconium by co-extrusion. The extrusion billet of uranium or uranium alloy is surrounded by a zirconium or Zircaloy 2 sleeve and fitting end pieces. Both core and cladding are then enclosed in an evacuated and sealed copper can about 0.040 in. thick. The complete assembly is then extruded using a conical approach to the die orifice. All the materials should be fine grained to start with and extrusion

is carried out in the high  $\alpha$ -phase temperature range, about 640°C. Co-extrusion eliminates the separate preparation and close matching of both core and cladding, provides an integral bond and makes possible the use of thinner cladding than required for separate sheaths. Any heat-treatment necessary on the fuel for radiation stability may be applied to the whole assembly after extrusion.

Dispersion systems have shown impressive burn-up performances without becoming unmanageable in the reactor. More than 80% of the fissile atoms in the  $UAl_4/Al$  system can be burned without difficulty and a burn-up of more than 50% leaves the system  $UO_2$ /stainless steel still dimensionally stable.

### Ceramic fuels

The resistance of ceramics to radiation damage and their general strength properties under reactor conditions are encouraging. At the same time, they have a lower fissionable-material density than the pure metal fuels and they are prone to thermal shock and brittle failure. Provided the pieces can be held closely together in some way, the actual cracking need not introduce new problems of dimensional instability, but it does mean, under such conditions, that no reliance can be placed on the fuel from a load-bearing point of view. The fuel will require substantial canning, which will also prevent fission products being released to the coolant.

Ceramics generally have considerably lower thermal conductivities than metals. This is one major factor contributing to their poor resistance to thermal shock. Thus, at the high heat-extraction rates which might be required in a reactor, the temperature gradient across a fuel element cross-

section will be steep. If fusion at the centre of the fuel element is to be avoided, thinner sections will have to be used than is the case for the metal fuels. This inevitably leads to increased cost of fabrication of the fuel on a unit weight basis and necessitates larger quantities of expensive canning materials.

The fissile ceramics do not exhibit anisotropy in their structure or properties, and phase transformations can be avoided in most of the useful fuel systems. The systems which have received most attention are the uranium carbides and uranium oxides. The carbides have better thermal conductivities than the oxides but are inherently less stable. Even the oxides are not universally stable, particularly with respect to oxygen, but they have received more attention than the carbides.

#### Uranium oxides

The development of uranium dioxide as a possible reactor fuel started with the discovery that it had good corrosion resistance to high-pressure water up to 300°C. The development then turned to using the system in a high-temperature gas-cooled reactor because of superior resistance to radiation damage.

There is a wide range of oxides of uranium:  $\text{UO}$ ;  $\text{UO}_2$ ;  $\text{U}_4\text{O}_9$ ;  $\text{U}_2\text{O}_5$ ;  $\text{U}_3\text{O}_8$ ;  $\text{UO}_3$  and others. The most stable is  $\text{UO}_2$  and this is the one preferred. Even then, the formula  $\text{UO}_2$  is not entirely accurate, since the oxide has a defect structure which will allow an extra 10% of oxygen to be absorbed so the composition varies from  $\text{UO}_2$  to  $\text{UO}_{2.25}$ . The properties of the dioxide are very dependent on the degree of this non-stoichiometry.

Massive uranium dioxide is prepared from powder and there are several ways of producing the original powder. Uranyl nitrate hexahydrate may be treated with hydrogen peroxide to precipitate  $\text{UO}_4$  which is then reduced in hydrogen at a temperature of 650–850°C. to give  $\text{UO}_2$ . Similarly, ammonium diuranate may be calcined in nitrogen at 700°C. to  $\text{UO}_3$  and this reduced to  $\text{UO}_2$ . Alternatively, uranium may be oxidized direct to  $\text{UO}_2$  in steam at 350° or to  $\text{U}_3\text{O}_8$  in air followed by hydrogen reduction, but since the two salts mentioned above may be formed *en route* to releasing uranium metal it is more economical to use them for  $\text{UO}_2$  production.

Cold pressing and sintering, hot pressing, extrusion and slip casting have all been used successfully in fabricating  $\text{UO}_2$ , but the preferred technique appears to be cold pressing and sintering, although this produces material with a density of up to 95% of the theoretical compared with up to 98% for hot pressing. The disadvantage of hot compacting is the rapid die wear and complexity of atmosphere control.

Cold compacting may be carried out in steel dies after ensuring dense packing of the powder prior to pressing. Binders may be added to  $\text{UO}_2$  to increase the green strength of the cold-pressed compact. These include polyvinyl alcohol, polyethylene glycol, paraffin waxes and camphor—all of which volatilize during sintering. With all but small simple compacts there is difficulty in obtaining a uniform distribution of the compacting forces throughout the mass. This is overcome to some extent by packing the powder into a rubber former and subjecting the whole assembly to isostatic pressing.

The density of the final compact after sintering is very dependent on the condition of the original powder. A powder with high initial density, large surface area and non-stoichiometry sinters to the highest density *in vacuo* or in inert atmospheres, but there is little advantage in having non-stoichiometry when sintering in hydrogen. Normally, the defect structure associated with non-stoichiometry accelerates sintering.

The density of the compact is also sensitive to the sintering temperature. Depending on particle size, sintering is normally carried out at between 1,400°C. and 2,100°C. The large surface area of sub-micron powders allows very rapid sintering rates compared with coarse powders, but fine powders tend to give considerable shrinkage during shrinking. The time of sintering beyond the first few hours does not appear to be very important. The density produced by compacting followed by sintering normally approaches 95% of theoretical but 96% may be achieved with isostatic pressing non-stoichiometric fine powder and sintering first in argon and then in hydrogen at 1,750°C.

Shrinkage occurs during sintering and unless the powder is very strictly controlled it is not possible to predict the dimensions accurately. For maximum control of shrinkage, the powder must have high initial density, a low surface area and a particle-size distribution which will allow a close approach to ideal packing prior to pressing. Normally, it is easier to grind or machine the compact to the correct dimensions after sintering, using diamond or carbide tools. Shrinkage is more controllable in hot-pressing because the compact is still under pressure in the die at or near to its sintering temperature. Induction-heated graphite dies in a controlled atmosphere are normally used in this process but die life is short. Pressures of the order of 1 ton/sq. in. are used at temperatures in the range 1,400–2,000°—usually 1,700°C.—to give compacts of density up to 98% of the theoretical.

Some of the important properties of uranium dioxide are given in Table 17, from which it will be seen that the material has a high melting point,

TABLE 17 Some physical properties of  $UO_2$  and  $UC$ 

	Dioxide	Carbide
Melting point ..	2,800° C.	2,375° C.
Density by X-rays ..	10.95 g. c.c.	13.63 g. c.c.
Thermal conductivity	0.02 (at 20° C.) cal.-cm./°C.- cm. <sup>2</sup> -sec.	0.078 (at 44° C.) cal.-cm./°C.- cm. <sup>2</sup> -sec.
Specific heat ..	0.056 cal. g./ °C. (0-200° C.)	—
Structure .. ..	F.C.C.	F.C.C.
Metal atom c.c. com- pared with metallic uranium .. ..	51.5%	95.19%

a simple crystals structure but relatively low thermal conductivity which decreases with increasing temperature. In detail, some of the properties vary according to the degree of non-stoichiometry of the dioxide. For instance, the stoichiometric oxide has a lower volatility and less plasticity at high temperatures and a higher thermal conductivity than the non-stoichiometric version. When  $UO_2$  is heated in air it reacts exothermically to give progressively  $U_2O_3$ ,  $U_3O_7$  and  $U_3O_8$ , the latter being found at about 600° C. Some extremely fine  $UO_2$  powders are sufficiently reactive in air to be pyrophoric. On heating to higher temperatures oxygen is driven off until  $UO_2$  becomes the stable form again above 1,100° C. Since density changes are involved in these transformations, uranium oxide thermally cycled in air would be expected to fail by thermal shock. The stoichiometric dioxide is compatible with the inert gases, nitrogen, hydrogen, sodium and pressurized water at 300° C. In water reactors the dioxide is clad in Zircaloy and at very high heat ratings it is possible for some slight reaction to take place between the oxide and the can.

The effects of irradiation on uranium dioxide are very encouraging. Whereas through wrinkling, growth, phase transformations and swelling, natural uranium is dimensionally unstable under irradiation, uranium dioxide is dimensionally stable for irradiations far in excess of those which would extensively damage the pure metal. The oxide shows little loss of strength below 1,000° C. and is therefore able to resist swelling very effectively. Nevertheless, fission-product gas released within the oxide is at a very high pressure, and this, together with thermal stresses, results in gross cracking. Present evidence suggests that the best irradiation resistance and least release of fission products is achieved with the highest density  $UO_2$ . A subsidiary reason for requiring the highest density is that  $UO_2$  of full theoretical density contains only just over half the

number of uranium atoms contained in the pure metal on a comparable volume basis. The dilution of uranium in this way requires correction by enrichment with respect to fissile uranium and the situation is only made worse by using uranium dioxide of low physical density.

Uranium dioxide may be dispersed in other ceramics for reactor fuel purposes.  $UO_2$  dispersed in oxides such as zirconia, magnesia, alumina, beryllia and thoria have been studied.

### Uranium carbides

Uranium forms three carbides,  $UC$ ,  $UC_2$  and  $U_2C_3$ , but the latter is unstable except under special conditions and the  $UC_2$  reacts with moisture. The monocarbide is therefore of most interest, particularly since it has the greatest volume fraction of uranium. It has a greater density of uranium per unit volume than the dioxide, and also superior thermal conductivity and thermal shock resistance.

The carbides are formed into massive pieces by powder methods in much the same way as described for uranium dioxide. The carbide can be made by reducing uranium dioxide with graphite at about 1,800° C. for a few hours or by sintering a cold-compacted mixture of uranium and graphite at 1,050° C. *in vacuo*. Hot pressing of uranium and graphite powders at 650-1,000° C. with loads in the region of 10-20 ton/sq. in. also produces the carbide. Densities up to 98% of the theoretical are attainable by these methods. Mixtures of uranium and graphite powders may be extruded in an inert atmosphere at temperatures of the order of 1,000° C.

From Table 17 it will be seen that the carbide has a simple face-centred cubic structure and melts at about 2,400° C. The thermal conductivity is comparable with that of uranium metal and, although this decreases with temperature, the decrease is not as serious as for uranium dioxide. The mechanical properties of the carbide are also superior to those of the dioxide, at least at room temperature. The resistance of uranium carbide to oxidation in  $CO_2$  or in boiling water is poor. Up to 700° C., uranium carbide oxidizes faster than uranium in  $CO_2$  but at higher temperatures the order is reversed. The major effect of irradiation on uranium carbide is cracking accompanied by partial release of fission gases, but dimensional changes due to plastic deformation do not occur under practical reactor conditions.

### Other ceramics

Uranium nitrides, silicides and sulphides have been studied for possible reactor use, all having melting points of 1,700° C. or more. Two plutonium oxides,  $PuO_2$  and  $Pu_2O_3$ , are of interest, the former being isomorphous with  $UO_2$  and having a melting



point about 2,200°C. The carbides of plutonium PuC and Pu<sub>3</sub>C<sub>2</sub> are also isomorphous with the corresponding uranium carbides.

### Liquid fuels

It is quite obvious that several of the difficulties associated with solid fuels, particularly growth and swelling, would be overcome by the use of a liquid fuel which has no directional properties and releases fission product gases readily. Continuous processing of the fuel would be possible and, because of the absence of much of the irradiation damage, a burn-up of a very high order should be possible. Early adoption of liquid fuels has been delayed by the difficulty of finding a uranium alloy with a sufficiently low melting point and containing sufficient fissile material. It seems that enriched uranium will be necessary to give satisfactory working conditions. If enrichment is considered, then it is possible to use low-melting-point metals saturated with uranium.

Of the various possibilities, bismuth appears to be the best. It has a relatively low neutron-capture cross-section and it is possible to dissolve enough pure U233 in molten bismuth to maintain the chain reaction. The core of the reactor might consist of graphite with channels through which the U-Bi alloy would be pumped. It has also been suggested that a suitable material for the reactor vessel would be a chromium-molybdenum steel which has good resistance to bismuth corrosion. The liquid alloy would pass to a primary heat exchanger where it would give its heat to an intermediate liquid-sodium circuit which would transmit the heat from the reactor. It would not be possible to exchange the reaction heat directly from the bismuth alloy to the steam generator without greatly extending the screening of the reactor.

The major difficulty with liquid-metal fuels, or liquid metals generally, is mass transfer. This occurs by solution of soluble constituents of the containment system in the liquid metal at the highest temperature part of the system and deposition of the corrosion product at the coolest part. The mass transfer is greatest when there is a large difference in solubility between the high and low temperature parts of the system and with a large range of temperature between maximum and minimum. Mass-transfer difficulties are also discussed in a later section dealing with miscellaneous reactor corrosion problems.

In view of mass-transfer effects, the containment material for a liquid fuel system must be chosen carefully. For instance, the solubilities of iron, chromium and nickel in bismuth at 550°C. are significant, particularly that of nickel (Fe and Cr each about 25 p.p.m. but Ni about 0.05 wt. %). Thus it would appear that nickel-containing

materials would be unsuitable in containing a bismuth-uranium liquid fuel system. Even ferritic stainless steels display measurable mass transfer of iron and chromium in bismuth. Low-alloy steels, such as 2½% Cr-1% Mo steel, are much more attractive from a corrosion point of view and have a useful life in liquid bismuth up to 550°C. At higher temperatures it is necessary to consider more refractory metals such as molybdenum and tantalum.

Experience with uranium-liquid metal systems should accelerate any required development of liquid-plutonium alloy systems. Plutonium, having a lower melting point than uranium, may lead to a wider choice of alloys (see Table 18).

An alternative to completely liquid fuels is to hold alloyed fissile metals at temperatures in the liquidus-solidus range of the alloy where it will be only partly molten, or to mix insoluble particles in a melt. As an example of the latter, USn<sub>3</sub> in liquid Pb-Bi-Sn, UPb<sub>3</sub> in lead and UBi<sub>2</sub> in bismuth are possibilities. These slurries can hold larger quantities of fissile materials at practicable temperatures than can true melts. One large difficulty of these systems is that with temperature gradients there will be continual changes in the solid particles in number, size, shape and distribution, apart from mass-transfer effects. Some of the difficulties of variable solubility slurry systems are overcome by employing insoluble solids in liquid metals, such as UO<sub>2</sub> in bismuth or ThO<sub>2</sub> in bismuth.

### Plutonium as a reactor component

Fission of Pu<sub>239</sub> produces a high average yield of three neutrons per atom and this makes plutonium particularly applicable to use in breeder reactors.

Attempts to irradiate pure solid plutonium to produce large heat release rates would result in large shape and volume changes while its low melting point would probably lead to melting at

TABLE 18 Low-melting-point Pu alloys

Composition (w/o)	Melting point (°C.)
Pure Pu	635 <sup>1</sup>
96 Pu 4 Ni	465 <sup>1</sup> 475 <sup>2</sup>
86.8 Al 13.2 Pu	647 <sup>1</sup>
35.5 Mg 64.5 Pu	552 <sup>1</sup>
97.7 Pu 2.3 Mn	510 <sup>2</sup>
91 Pu 9 Os	495 <sup>2</sup>
96.8 Pu 3.2 Fe	430 <sup>2</sup>

<sup>1</sup>R. J. Teitel, 'Composition and Properties of Liquid Metal Fuels,' U.S. Government Printing Office.

<sup>2</sup>S. T. Konobeevsky, U.S.S.R. Academy of Sciences publication (4955) on P.U.A.E.



the centre of the piece. Additionally, plutonium has a high cross-section to thermal neutrons so that in a pure plutonium element, unless it was very thin, the outer layer would absorb all the neutrons and little use would be made of the core materials. This situation might be improved somewhat by using fast neutrons, but even then it is doubtful whether a high energy output could be achieved without extensive damage to the fuel element. Solid plutonium in mild-steel cans has been tried as a fuel element in the Los Alamos fast reactor experimental neutron source. After about four years a fuel element failed and the subsequent decontamination of the reactor was very difficult and hazardous.

Dilution of plutonium with uranium or thorium—in either case the reactor is then an internal breeder reactor—or with suitable non-fissile metals is a more feasible approach to the production of fuel elements. For instance, to energize a thermal reactor, about 2% or less of plutonium dispersed throughout the fuel elements would be sufficient. For a fast reactor, something like 20% plutonium

would be needed. The actual fuel element construction and arrangement in the reactor would probably conform largely to present practice and developments on uranium fuel elements.

As the amount of plutonium in a fuel element is not excessive there is a reasonable choice of suitable matrices to carry it, but the matrix must not have a high neutron-capture cross-section. The actual matrices will depend on the type of reactor for which the fuel will be used. Plutonium-aluminium alloys have already received considerable attention in research reactors and plutonium-zirconium for water-cooled systems. It is not necessary for the fissionable component to be metallic. For instance, the uranium ceramics,  $UO_2$  and  $UC_2$  might be boosted with  $PuO_2$  and  $PuC$  respectively.  $PuO_2$  in alumina or  $PuC$  in zirconia are further examples of possible dispersions for high-temperature systems.

The limited information available on the irradiation behaviour of plutonium alloys and dispersion systems suggests that they are no worse than uranium fuels now in use.

## Heat processing stainless steels

*concluded from page 108*

to below a micron and raise the temperature to approximately 960°C. As rapidly as possible, bring the stainless steel to the flow point of the braze metal and then cool in vacuum atmosphere to prevent oxidation.

As we have said, there are many factors to be considered when selecting a vacuum furnace: Temperatures, pressures, heat-treat cycle, size of parts to be heat treated, necessary arrangement of parts during heating process, rate of production, quality and type of results desired, types of controls and instrumentation.

For specific processes, the user may desire the 'hot-wall' type of vacuum equipment which consists of a vacuum-tight retort heated by conventional furnace equipment, or he may want the double evacuated 'hot-wall' type which can operate at higher temperatures because the effect of atmospheric pressure is removed from the vacuum retort.

On the other hand, a 'cold-wall' type furnace may be the choice. This type has become popular because of its flexibility—its ability to operate at higher temperatures and lower pressures (than the hot-wall type), its speed of heating and cooling, its faster cycling, and its adaptability to almost any size of chamber. Equipment can be arranged so that the processing furnace is horizontal or vertical, or it can incorporate adjacent cooling chambers for quenching or cooling work. It can also be equipped

with mechanized conveyors to move work through various cycles, or it can be equipped with vestibules to admit and remove work from the atmosphere chamber without changing the environment in regard to temperature and pressure.

As for versatility, one company in the aircraft field reports that a furnace purchased only for nickel brazing of stainless steels is now hardening high-speed steels, brazing complex stainless steels, nickel-alloy plated (which are hardened and tempered in a single operation), and outgassing Hastelloy W parts and welding rods which are subsequently welded into an assembly.

Another company, in the electronics field, purchased a vacuum furnace for hardening beryllium copper. They now also use the furnace for hardening Ni-Span-C, and for annealing stainless steel. Vacuum equipment has also been used for brazing heat-exchanger tubes made of stainless steel, copper brazing and hardening of stainless-steel parts, and also for general heat-treatment work.

One company realized a great saving when a quantity of stainless-steel parts—long shafts with a gear assembly, copper brazed to the end—had to be remachined or remade because of a change in specifications. They were able to anneal the parts in 'vacuum atmosphere' and thus re-machine them, and then harden and temper them in vacuum.

Another vacuum furnace, originally built for brazing and annealing stainless, was later used for annealing tantalum above 1,370°C., and has now been changed for firing ceramic semiconductor wafers.

## Russian forging journal

*Abstracts from the Russian forging journal — 'Kuznechno-Shtampovochnoe Proizvodstvo,' August, 1960, 2. This is the second year of this journal devoted specifically to forging. We shall try to give indications of the contents of future numbers in METAL TREATMENT each month.*

*The manufacture of turbine disc forgings from centrifugally cast billets. A. V. ALTYKIS. Pp. 1-7.*

The investigations carried out show that the proposed technical process ensures production of good quality forgings, and that it is also more convenient under production conditions, because it is possible to use a whole heat for casting a long centrifugally cast billet which can be cut up into suitable lengths for forging. Disc-type forgings so produced give an 18-20% saving in metal consumption by comparison with their production from an ingot, with a considerable reduction in the cost of the finished forging.

*Hot sizing of press forgings. F. V. KUTSOVSKII and P. G. PAL'CHEV. Pp. 7-9.*

Sizing dies and methods of sizing are outlined for the production of caliper frames.

*Calculation of the technical parameters of the torsion shearing operation for round bar stock and tubes. P. E. KISLYI. Pp. 9-14.*

The method may be employed without prior heat treatment to cold metal, unless previously quenched and tempered. By comparison with press shearing there is a marked absence of pits and cracking on the end faces which are strictly perpendicular to the axis of the stock. The degree of twist required may be between 25 and 120° dependent on the working conditions considered in the article. For short tube lengths a bung should be used according to the internal diameter of the stock.

*Automation of the heating and stamping of tractor and automobile valves. E. G. BORODULIN. Pp. 14-18.* Electro-pneumatic automation circuits and systems are outlined for stamping valves on forging presses with single and double grab transfer mechanisms.

*Design of dies for compressor blades. V. G. CHIZHOV. Pp. 19-21.*

*The application of line networks to sheet blanks before stamping. YU. P. KAZAKOV. Pp. 21-22.*

*Vibrations in the bedplate of forging hammers with various degrees of insulation of their foundations against vibration. V. F. SHCHEGLOV. Pp. 23-27.*

Vibrational damage problems and methods of damping of vibrational effects are discussed in the light of experiments of the author and of H. W. Koch (see *Stahl und Eisen*, 1958).

*Modernization of a 100-ton hydraulic press. A. A. ULBABYANTS. Pp. 27-31.*

*Mechanization of spinning lathe operations. YU. P. SOGRISHIN and YA. I. AVERBYKH. Pp. 32-34.*

Sogrishin and Averbykh describe the spinning of thin-walled conical and cylindrical components from aluminium alloys.

*A vibrational striker mechanism for knocking out wedges. I. I. BARBER. Pp. 34-37.*

*A new walking beam-heating furnace. V. V. PETROVICHEV. Pp. 38-40.*

*A low inertia friction clutch employing Retinax material. L. A. PRISHCHEPIONOK. Pp. 41-42.*

A clutch for stamping and forging press drives is described.

*Improvements in handling devices for forging. M. L. BORINSKII. Pp. 42-45.*

*A combined die. A. M. KULAKOV and A. G. KOKIN. P. 46.*

A. G. Kokin's design for a die makes it possible to produce a wheel stuffing box cover in one operation instead of four.

*Experience in the stamping of thin components of instruments in an aluminium die. YU. M. RUDNEV. Pp. 46-47.*

Stamping of components of complicated outline  $\leq 0.2$  mm. in thickness is described.

# Effect of carbide stringers on the distortion of die steels during heat treatment

K. SACHS, Ph.D., M.Sc., A.I.M.

*The causes and mechanism of distortion of die steels during heat treatment, the influence of the structure of the steel and in particular the part played by carbide stringers, are studied. The author is Head of Research Metallurgy Section, G.K.N. Group Research Laboratory, Wolverhampton, and his article will be continued in future issues*

*continued from last month*

MARTEMPERING.<sup>14, 20</sup> It has been explained in an earlier section that stresses and distortion arise in the hardening of steel because the changes in dimension and mechanical properties associated with the formation of martensite occur first in the parts that are cooled most rapidly to the  $M_s$  temperature. Rapid quenching produces severe temperature gradients and this increases the interval of time and temperature between martensite formation in different parts of the component. The stresses arising from these temperature gradients can lead to distortion and cracking, particularly in complicated shapes with sharp changes in section.

This can be overcome by eliminating the severe temperature gradients in a martempering treatment. The component is transferred from the hardening furnace to a lead or salt bath at a temperature above  $M_s$  at which the austenite is comparatively stable. The rate of cooling is extremely rapid and transformation to pearlite is suppressed. The temperature gradient during cooling is at least as sharp as in oil quenching, but the temperature is equalized in the lead bath before transformation occurs, so that only cooling stresses can be set up and these are reduced by recovery and relaxation of the soft austenite. When the temperature of the component is uniform, and before the austenite has started to

transform to bainite, the component is taken out of the lead bath and allowed to cool in air. While it passes through the temperature range in which transformation to martensite takes place the cooling rate is slow and the temperature gradient is correspondingly low; the transformation stresses are much less than in oil quenching, the risk of cracking is diminished and distortion is reduced.

A steel with 13% Cr and 2½% C has an  $M_s$  temperature of 210°C.; between 500 and 400°C. austenite is stable almost indefinitely (longer than 24 h.), but there is an intermediate transformation in the range 350 to 250°C. which starts after 5–8 min. and is virtually complete in 2–3 h.: 10% transformation occurs in about 20 min. Holding times in martempering must not exceed 10 to 15 min. if the full hardness is to be attained. Slight fluctuations in composition will lead to some variation in these transformation times. In marquenching large dies it may not always be possible to attain a uniform temperature in a holding period which completely avoids bainite formation.

Although martempering is intended to reduce distortion due to geometrical factors, it seemed worth investigating how specimens designed to reveal distortion due to variations in carbide distribution responded to martempering. Different treatments were carried out on specimens of both designs cut from various forged bars; some of

TABLE 8 Comparison of distortion figures of oil quenched and martempered specimens

Treatment	% Bainite (estimated)	Distortion specimen				
		1	2	3	4	5
Oil quench ..	0	+ 4.1	+ 5.7	+ 5.6	— 5.3	+ 5.5
10 min. 280°C. ..	1–5	+ 2.8	+ 3.8	+ 4.2	— 7.7	+ 6.0
35 " 250°C. ..	35–40	+ 3.3	+ 3.2	+ 3.4	— 7.6	+ 7.4

these treatments were short enough to produce a fully martensitic structure, others allowed a small proportion of bainite to form.

The type of specimen illustrated in fig. 26 was used in two martempering treatments and the distortion figures are compared with the average values of six oil quenches in Table 8.

Martempering appears to have slightly different effects on angle and T-section specimens. In specimens 1-3 the distortion produced by martempering is somewhat lower than the average of the distortion measurements after six oil hardening treatments, while in specimens 4 and 5 martempering results in distortion a little above that average. In all cases the distortions after martempering are within the scatter band of the other results and statistical tests indicate that the number of experiments carried out was not sufficient to establish significance. There may have been a slight tendency to counteract distortion produced by geometrical factors and the mass effect in quenching, but martempering evidently had no influence on distortion produced by differential expansion due to variations in structure in different parts of the component.

Other treatments were carried out on the modified type of specimen (fig. 27). More than one batch of specimens had to be used because repeated distortion and grinding of a specimen gradually reduces the thickness and this cannot be taken too far if one wants to compare the results of later tests with earlier ones. For each batch the distortion after oil quenching from a salt bath was determined as well as the effect of different martempering treatments. Most of the martempering treatments were repeated on at least two batches of specimens to ensure that the results were cross-checked.

The results are presented in Table 9. Martempering has had no dramatic effect on the distortion characteristics. There is no systematic decrease, nor is there a consistent change in the balance such as

was observed in gradient quenched specimens. The object of martempering is to diminish the stresses that give rise to distortion due to geometrical factors; it would be too much to expect it to influence the distortion arising from differences in carbide distribution as well. Unfortunately the distortion due to geometrical factors is not as easy to distinguish from other sources of distortion as might be wished. In forged bars where the structure in the centre is fairly uniform, specimen *B* (fig. 27) distorts under the influence of geometrical factors only, but in some of the forged bars the segregate is not accurately in the centre and specimen *B* overlaps into zones where coarse carbides are aligned in the direction of forging; it will be shown later that this asymmetry originates in the ingot, possibly as a result of slightly uneven cooling. In cases where specimen *B* shows appreciable distortion (greater than 5, for instance) after oil quenching, differences in carbide structure must play their part, and the influence of martempering is difficult to assess. Where the distortion of specimen *B* is due to geometrical factors only it is so slight that an improvement due to martempering would be difficult to detect.

It may be possible to discount the effect of carbide distribution on distortion, and assess the influence of martempering treatments on distortion due to geometrical factors, by comparing the arithmetic mean of the distortion indices of a group of specimens after various treatments (Table 10). The influence of the carbide structure should be similar in all these treatments, so that differences in the mean value should be caused by geometrical factors, modified by the nature of the heat treatment. This type of evaluation also allows different martempering techniques to be compared.

Some improvement in distortion appears to have been achieved by martempering for 35 min. at 250 C. and for 10 min. at 400 C. The other

TABLE 9 Effect of martempering

Martempering treatment	Bainite % (estimated)	Billet	Distortion				Distortion of the same specimens after oil quenching			
			Specimen							
			A	B	C	D	A	B	C	D
10 min. 200° C. *	20	ADB (A)	- 19.9	- 7.5	- 5.7	- 4.5	- 7.0	+ 16.3	+ 7.1	+ 2.7
		ADB (B)	- 4.3	+ 4.8	+ 7.8	+ 1.8	- 3.9	- 11.6	+ 4.4	
		ADW (A)	- 16.0	- 2.0	- 0.7	- 13.7	- 20.7	+ 13.0	+ 13.7	- 2.4
		ADW (B)	- 24.6	+ 0.7	+ 0.9	- 6.3	- 14.0	+ 3.6	+ 12.3	+ 1.4
35    "    250° C.	25	AAK	- 9.3	- 2.2	+ 11.6		- 13.9	+ 1.8	+ 12.5	
		ADW (B)	- 14.1	+ 12.3	+ 8.8	- 9.6	- 23.2	+ 8.1	+ 8.6	- 7.7
5    "    280° C.	0		- 27.3	+ 2.2	+ 10.3	- 3.6	- 26.5	+ 2.5	+ 11.5	- 4.4
		AAK	- 10.7	+ 2.7	+ 16.3		- 13.9	+ 1.8	+ 12.5	
10    "    280° C.	5	ADW (B)	- 10.2	+ 18.7	+ 2.4	- 2.6	- 23.2	+ 8.1	+ 8.6	- 7.7
			- 19.2	+ 7.4	+ 6.6	- 2.4	- 26.5	+ 2.5	+ 11.5	- 4.4
10    "    400° C.	0		- 17.2	+ 13.5	+ 16.0	- 1.5	- 20.7	+ 13.0	+ 13.7	- 2.4
		ADW (B)	- 22.3	+ 1.0	+ 19.9	+ 6.1	- 14.0	+ 3.6	+ 12.3	+ 1.4
60    "    530° C.	0									
		ADW (A)								

\*About 20% martensite formed in cooling



TABLE 10 Comparison of arithmetic mean of distortion indices

Martempering	Bainite %	Billet	$A + B + C (+D)$ 3 (4) (neglecting signs)	
			Oil quenched	Mar- tempered
10 min. 200 C.	20	ADB (A)	8.3	9.4
		ADB (B)	6.6	5.6
		ADW (A)	12.4	8.1
		ADW (B)	7.8	8.1
35 " 250 C.	25	AAK	9.4	7.7
5 " 280 C.	0	ADW (B)	11.9	11.2
			11.2	10.8
10 " 280 C.	5	AAK	9.4	9.9
10 " 400 C.	0	ADW (B)	11.9	8.5
			11.2	8.9
1 h. 530 C.	0	ADW (A)	12.4	12.0
		ADW (B)	7.8	12.3

treatments had no consistent effect and, in view of this, it is difficult to ascribe much significance to the moderate improvement produced by the above two treatments. Any effect of martempering is extremely slight and tends to be masked by random variations.

The outer specimens, A and C, usually distort by an equal amount in opposite senses; the algebraic sum of the distortion indices should be zero. Deviations from zero may be due to displacement of the centre-line of the distortion specimen away from the plane dividing the two outer layers of the macrostructure. However, gradient quenching, which can be regarded as greatly accentuating the influence of geometrical factors, also displaces the balance of the distortion indices of specimens A and C. If the deviation from zero of the value  $(A + C)$  in the oil-quenched condition is attributed to the macrostructure of the specimen, any changes in this deviation due to martempering can fairly be ascribed to the effect of this treatment on distortion under the influence of geometrical factors.

When the distortion indices in Table 9 are evaluated in this way, the various martempering treatments can be compared (Table 11).

The outstanding observation is that martempering at 200 C. has accentuated the distortion appreciably. This is not likely to be due to bainite formation because other treatments that also allow bainite to form do not cause similar increases in the severity of distortion. It seems more likely, therefore, that the effect of quenching into a salt bath at 200 C. is the result of the interruption of an extremely rapid quench at a stage where about 20% of the

volume has already transformed to martensite during cooling from the  $M_s$  temperature, 210°C. During this short period at 200 C. all the stress imposed on the austenite by the formation of martensite in adjacent areas can relax by the gradual deformation of the specimen. Thus, distortion due to geometrical factors is accentuated by an interrupted quench within the martensite range.

Of the other martempering treatments, some appear to have no appreciable effect on distortion: 35 min. at 250 C. and 10 min. at 280 C. Martempering for 5 min. at 280 C. seems to have produced a slight improvement, but it is not very pronounced nor fully consistent. The treatments at 400 and 530 C. hardly come into normal martempering practice. The austenite is very stable in this temperature range, but the cooling curve passes through a zone on the TTT diagram corresponding to rapid transformation to bainite. It has not been possible to ascertain whether any lower bainite formed on cooling. A slight improvement in distortion behaviour has apparently been achieved.

It can be concluded that martempering has only a marginal effect on the distortion of specimens of this type. This is, no doubt, due to their relative insensitivity to geometrical factors. There is little doubt that in engineering components and dies of complex shape, and particularly where the sections involved are heavier, martempering has a significant effect in reducing distortion.

It has been shown that gradient quenching imposes an additional distortion component in oil quenching and that this is associated primarily with the martensite transformation (Table 12). In tempering there should be an opportunity for the temperature to become uniform before the marten-

TABLE 11 Comparison of martempering treatments

Martempering	Bainite %	Billet	$A + C$	
			Oil quenched	Martem- pered
10 min. 200 C.	20	ADB (A)	+ 0.1	- 25.6
		ADB (B)	+ 0.5	+ 3.5
		ADW (A)	- 7.0	- 16.7
		ADW (B)	- 1.7	- 23.7
35 " 250 C.	25	AAK	- 1.4	+ 2.3
5 " 280 C.	0	ADW (B)	- 14.6	- 5.3
			- 15.0	- 17.3
10 " 280 C.	5	AAK	- 1.4	+ 5.6
10 " 400 C.	0		- 14.6	- 7.8
			- 15.0	- 12.6
1 h. 530 C.	0	ADW (A)	- 7.0	- 1.2
		ADW (B)	- 1.7	- 2.4



TABLE 12 Distortion effect of gradient quenching billet ADX (B)

Treatment	Distortion specimens		
	A	B	C
Salt bath (uniform temp.), oil quench	- 14.0	+ 3.7	+ 12.3
50° C. gradient, oil quench	- 3.5	+ 8.0	+ 14.4
50° C. gradient, martempered 10 min. 200° C.	- 13.8	+ 7.9	+ 16.8
50° C. gradient, martempered 5 min. 280° C.	- 16.0	+ 12.7	+ 22.3

site transformation starts and the additional distortion due to gradient quenching should be suppressed by martempering.

The experimental results indicate no improvement—no elimination of the additional distortion component as a result of martempering, except in the case of specimen A where the positive component was beneficial in that it balanced a negative component due to carbide distribution. It is not really surprising that the treatment at 200° C. did not have the desired effect, because it allows martensite formation to start on cooling. The other treatment, 5 min. at 280° C., is theoretically a more satisfactory martempering, but it is possible that full temperature equalization is not achieved in 5 min.

#### Modifications of the carbide structure<sup>18, 20</sup>

Vertical or horizontal quenching and martempering influence the geometrical distortion factors and are best studied with special specimens or dies having rather heavier cross-sections. The distortion specimens illustrated in figs. 26 and 27 were specially developed to reveal the influence of carbide

distribution and are obviously most suited to a study of methods of modifying the carbide structure with a view to reducing the susceptibility of the steel to distortion. Slight differences in structure in adjacent layers have been shown to cause distortion and a more uniform carbide distribution should therefore improve the stability of the steel in hardening. The structural characteristics likely to be relevant are particle size of the chromium carbides, the distribution of the carbide, which can be expressed in terms of the mesh size of the carbide network, and the directionality of the alignment. All these are likely to be influenced by forging and can be studied by deliberately modifying the forging technique and by experiments with cast structures.

Distortion tests were carried out on specimens cut from 2½-in.-square bar forged down from 5-in.-square ingots by different methods. These had to be correlated with the influence of different procedures on the carbide structure. Some technique was required for assessing the carbide distribution so that different structures could be compared.

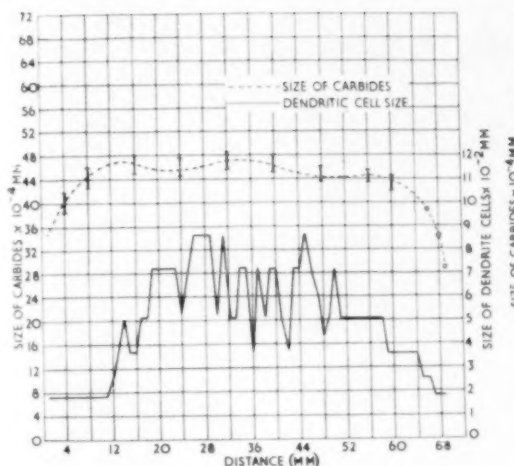
Metallographic surveys were made on 2½-in. long by ½-in. wide specimens machined from ingots and forged bars, and included most of the central macro-segregate. The dendritic cell size was determined by comparison with the standard A.S.T.M. grain size charts, and the sizes of the chromium carbides were measured on a microscope using a calibrated measuring eyepiece.

#### Effect of homogenizing anneal<sup>20</sup>

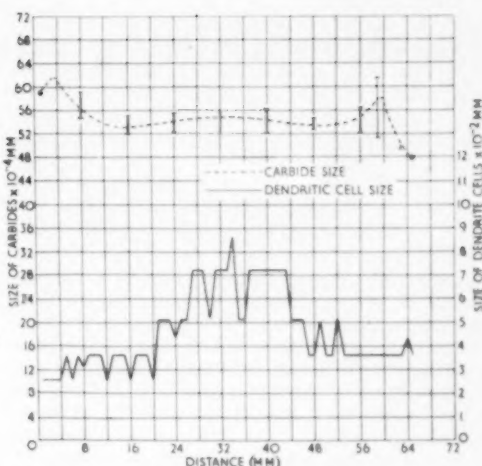
These techniques were also employed in a brief examination of the effect of prolonged homogenizing

TABLE 13 Effect of prolonged annealing

Billet	Annealing treatment	Heat treatment	Specimen		
			A	B	C
ACE 1	5 h. at 1,100° C.	Hardening: 1 h. at 960° C., oil quenched	+ 16.2	- 6.4	- 23.0
"	"	+ 1 h. at 200° C.			
"	"	Hardening: 1 h. at 960° C., oil quenched	- 25.5	- 7.4	+ 9.7
"	"	+ 1 h. at 200° C.			
"	"	Martempering: 1 h. at 960° C.	+ 12.1	+ 7.0	- 5.2
"	"	Martempered 10 min. at 200° C.			
"	"	+ 1 h. at 200° C.			
ACE 2	72 h. at 1,050° C.	Hardening: 1 h. at 960° C., oil quenched	+ 70.8	- 4.4	- 22.3
"	"	+ 1 h. at 200° C.			
"	"	Hardening: 1 h. at 960° C., oil quenched	+ 24.9	+ 10.9	- 2.5
"	"	+ 1 h. at 200° C.			
"	"	Martempering: 1 h. at 960° C.	+ 14.4	+ 5.9	- 18.4
"	"	Martempered 10 min. at 200° C.			
"	"	+ 1 h. at 200° C.			
ADW (C)	170 h. at 1,200° C.	Hardening: ½ h. at 960° C., oil quenched	- 25.2	- 2.1	+ 46.0
"	"	+ 1 h. at 200° C.			
"	"	Hardening: ½ h. at 960° C., oil quenched	- 14.2	- 0.6	+ 32.3
"	"	+ 1 h. at 200° C.			



33 Metallographic survey of Billet ADW(B) forged on a 600-ton press



34 Metallographic survey of Billet ADW(C) forged on a 600-ton press and then annealed for 170 hours at 1,200 C.

treatments of the forged bar on the distortion behaviour of specimens cut from the bars. In the high-carbon high-chromium die steels under consideration, chromium carbide forms as a primary phase from the melt and it is impossible to dissolve all of it in austenite because incipient melting would supervene. In view of the fact that high-temperature heat treatments have been successful in producing a more uniform carbide distribution<sup>21</sup> in high-speed steels (where a peritectic transformation occurs), some attempt was made to see what such treatments would do in the high-carbon high-chromium steel. Even though chromium carbide is in equilibrium with austenite at the solidus, its solubility increases with temperature; a high-temperature heat treatment will undoubtedly take some carbide into solution and re-precipitate it elsewhere. Such re-precipitation seemed likely to be random and might counteract the longitudinal alignment due to forging. It seemed worth finding out if this effect could be detected in the structure and distortion behaviour of the steel—and there was some hope, unfounded as it turned out, that the effect on distortion might be beneficial.

Since it was desired to modify the carbide distribution over the whole of the forged billet and not merely in the individual distortion test pieces, a suitable length of the billet was annealed before cutting up. Three different annealing treatments were tried and various precautions were taken to avoid excessive decarburization; the billet which was annealed at the highest temperature, 1,200 C., was nickel plated quite heavily. During annealing a diffusion layer with a very complex structure was

formed at the surface; this was removed before the distortion specimens were prepared. Details of the annealing treatments are given in Table 13.

The effect of the most ambitious annealing treatment on the carbide structure is illustrated by a comparison of the metallographic surveys of two billets forged under similar conditions, with and without a prolonged anneal at 1,200 C., in figs. 33 and 34. Evidently there has been a slight coarsening of the carbides and a reduction in the dendritic cell sizes, particularly in the intermediate zone between the central aggregate and the heavily worked outer layer. In fig. 34 there are two high peaks in the curve for carbide particle size near the edge of the section; this may be associated with the nickel-rich diffusion layer which formed in the anneal. The coarsening of the carbide particles suggests that annealing has indeed dissolved and re-precipitated some carbide but that the finest and most unstable particles have gone into solution first and that precipitation took place at the surface of existing particles. Some fresh nucleation seems to have occurred also, perhaps mainly at austenite grain boundaries, leading to a decrease in the apparent mesh size of the dendritic network.

It can be concluded that prolonged annealing at very high temperatures has a demonstrable effect on the carbide distribution, but it is obvious from Table 13 that the coarsening of the carbides is very detrimental to the distortion behaviour; in all cases the annealing treatment not only increased the distortion appreciably but also produced extremely variable results.

*to be continued*

## Spark machining equipment

*New Anglo-French company at Burnley*

SPARK EROSION is particularly suitable for machining materials which, because of their hardness or toughness, are difficult to machine by conventional methods. It can also be used on intractable materials, such as stellite, tungsten-carbide and magnet steel, to produce openings and cavities which might be impossible to form by ordinary machining methods. As there is no mechanical contact between electrode and workpiece, holes of any size or shape can be pierced in thin or delicate materials which would be deformed by the pressure of normal cutting tools.

The forming of irregular openings in forging blanking and extrusion dies is an important application of spark erosion. The practice of assembling numerous precision-ground pieces in order to form an irregular cavity in a die can be eliminated in favour of the one-piece homogeneous die. In the mass production of forging dies, as required in the motor industry for instance, spark erosion has proved to be an economical manufacturing method, not least because it yields consistent accuracy in new sets of dies. The inaccuracies of traditional die making can be eliminated and the tolerances permissible on finished forgings are thus available to allow for normal wear of the dies.

### Principles of operation

The essence of spark erosion is the production of spark discharge in the hydrocarbon oil across a small gap between two pieces of metal. The workpiece to be machined acts as the anode, and the equivalent of the cutting tool forms the cathode—usually referred to simply as the electrode. A spark is generated between electrode and workpiece when the potential difference across the gap is sufficient to overcome the dielectric strength of the medium so that an electrically conductive path is created. The cross-sectional area of the spark is very small and current density reaches very high values, producing spark temperatures of up to 13,000°C.

The energy is concentrated on the terminal areas of the spark path and, in a short duration spark, there is insufficient time for localized heating to penetrate into the metal. The heating is, however, such as to melt and evaporate the metallic particles

at the spark terminal areas and this, together with the powerful shock waves so generated, produces a localized micro-explosion which blasts material from the work surface and leaves a characteristic crater.

Crater size, and thus surface finish, is dependent upon the energy passed between electrode and workpiece. Thus, by altering the discharge value across the gap, the surface roughness can be adjusted to suit the degree of finish required. As the spark discharge progressively erodes both workpiece and electrode, the gap width is adjusted automatically by means of a servo-mechanism which feeds the electrode to the work in accordance with the conditions within the spark gap.

After the condenser has discharged across the gap, and while the dielectric fluid becomes 'de-ionized,' the condenser recharges until its voltage again reaches the breakdown voltage, thus repeating the cycle. The frequency of sparking is a function of the condenser capacity and the frequency of the full-wave rectified output of the single-phase alternator. Mechanical flushing away of debris is achieved by the explosive effect of the spark discharge, by vibration of the electrode and by high-pressure feeding of the dielectric fluid through the electrode.

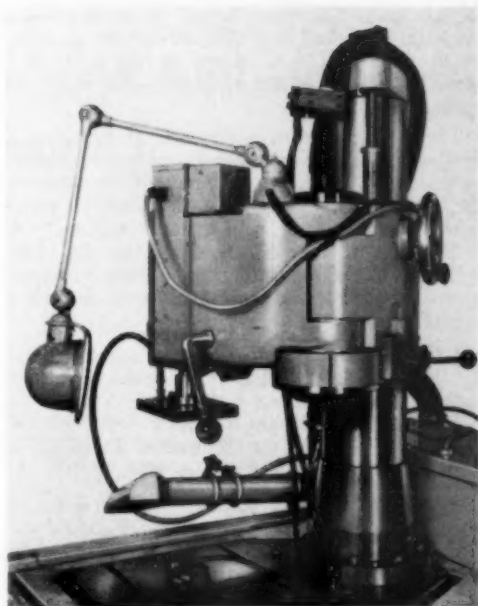
### Languepin spark erosion machines

The recent formation of a new Anglo-French company, Solar Weld Languepin Ltd., Fulleage Works, Burnley, Lancashire, has made available in the U.K. spark erosion equipment developed by the famous French company, La Soudure Electrique Languepin, of Paris.

There are three machines in the range, all embodying the Languepin design feature of auto-elevation retraction of the tank containing the dielectric. The Seleromat A has an erosion head mounted on an articulated arm which can be swung away to give uninterrupted vertical access over the whole area of the work table.

The Seleromat B is essentially similar, but has its erosion head mounted on co-ordinate slides which permit the accurate location of electrodes over any station of the workpiece area.

The Seleromic is the smallest of the three



1 The Servohead on the Seleromat A machine is carried on a knuckle-articulated arm which can be swung clear to provide free vertical access over the whole area of the work-table

machines and is a bench-mounted unit. It possesses a number of refinements not usually available in machines of this size.

A complete spark erosion machine installation comprises (i) the machine itself, (ii) the spark generator, which is housed in a separate cabinet and is connected to the erosion head by a screened co-axial cable and (iii) a filtration unit for removing micro-solids from the dielectric fluid.

**Seleromat A.** The base of the machine is of welded steel construction, it incorporates the supports for the work table and houses the 100-gal. dielectric tank and its pump mechanism. The dielectric tank completely surrounds the machine table and is raised and lowered electrically; the tank rises so that the dielectric submerses the work table, electrode and workpiece. The level of dielectric in the tank is maintained automatically, and auto-control gear ensures that the erosion head is inoperable unless the electrode is immersed. The work table measures 20 x 25 in. and has two T-slots for clamping bolts. The table will support workpieces weighing up to 1 ton.

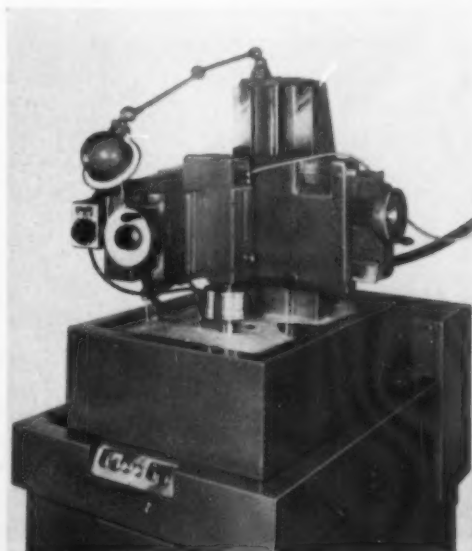
The electrode carrier and its servohead comprise an integral unit at the outer end of an arm which slides vertically and swings horizontally on a ground pillar rising from the base of the machine at the

rear. Vertical movement of the arm is controlled by a worm-driven telescopic screw, and quick-action levers clamp the arm on the pillar. Fine adjustment of the arm horizontally for electrode positioning is made through a simple screw device.

The servohead is carried in opposed V-slides and has a vertical travel of 4 in. Motion is derived from a split-field d.c. motor driving a leadscrew through a reduction gearbox, manual control being vested in a pair of push buttons on the front of the unit. Automatic downfeed is governed by electrical trips and the depth required can be pre-set on a micrometer scale to increments of 0.001 in., although the scale calibration is wide enough for this increment to be halved in practice.

The electrode carrier at the base of the servohead is electrically insulated, and a vibrator can be interposed which, having a vertical movement of 0.0005 in. at a frequency of 50 c./s., provides mechanical pulsation to assist in flushing eroded debris from the discharge area.

**Seleromat B.** The base and dielectric tank system are essentially similar to the A model, but the erosion head is mounted on precision co-ordinate slides providing 'jig-boring' positioning of the electrode over the workpiece. The co-ordinate movement dimensions are 9 x 12 in. The co-ordinate slide assembly is carried on twin scraped slideways on a massive column at the rear of the machine, vertical movement being controlled by a worm-driven telescopic screw.



2 Seleromat B machine showing dielectric tank fully raised



The longitudinal slide carries a saddle on which the transverse slide is mounted. The saddle is traversed by means of a precision leadscrew fitted with a large-diameter micrometer drum with vernier setting. Saddle locks are provided, together with precision longitudinal scales. The transverse slide has similar features to the longitudinal slide. The micrometer drums can be calibrated in 0.01 mm. or 0.001 in. gradations as required, and illuminated optical vernier equipment is also available for attaining the highest order of setting accuracy. The electrode carrier and servohead unit are the same as for the Seleromat A. Table size is 20 × 24 in. Capacity for both A and B machines is given in the table.

Capacity (with UE 2500 2M generator—2.75-in.-dia. copper electrode—steel specimen heat treated to ~56 Rockwell C)

Setting	Erosion rate (mm. <sup>2</sup> min.)	Surface finish (μ)	Tolerance (in.)
Roughing ..	1,000	50	0.004
Semi-roughing ..	140	18	0.003
Finish ..	9	5	0.001
Super-finish ..	2	2	0.0003

Spark discharge generator. The generator unit

for use with Seleromat A and B spark erosion machines is housed in a steel cabinet 83 in. high, 55 in. wide and 28 in. deep. Power is derived from a three-phase a.c. supply of 440 V. at 50 cycles.

The rate of erosion is selected by means of a four-position heavy-duty switch, the control handle of which is situated at the front of the cabinet; the settings are marked 'roughing,' 'semi-roughing,' 'finishing' and 'super-finishing.' A further feature allows control of the d.c. field excitation of the alternator; this results in a continuous control of the erosion rate over the entire operating range.

**Dielectric filter.** The high rates of metal removal by the Seleromat A and B machines require a copious supply of clean dielectric fluid to ensure good surface finish on the work. Mechanical filtration of the fluid at the rate of 11 gal. h. is obtained from the filtration unit.

The filter unit will remove particles down to 1 micron in size. It comprises 19 cylindrical elements built up from paper discs, the fluid entering the elements from the exterior and depositing its solids on the edges of the packed discs.

## NEW FILMS

### 'An Industrial Notebook on Iron and Steel'

A MISCELLANY OF ITEMS about the iron and steel industry, together with some interesting applications, both old and new, are featured in a recent film issued by Shell-Mex and B.P. Ltd.

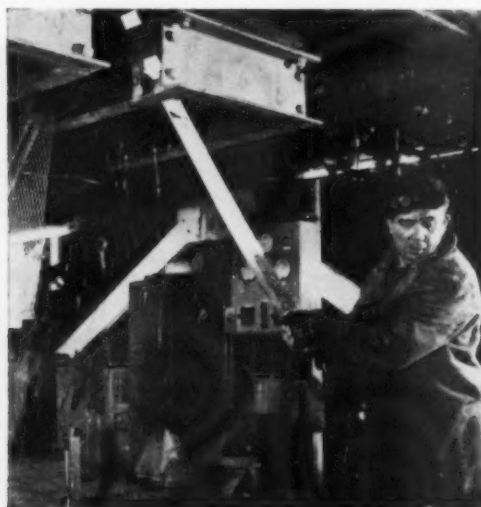
The film shows the early furnace at Coalbrookdale, used for smelting the iron in 1779 for the first iron bridge in the world, and contrasts a modern blast furnace handling a 250-ton cast and an electric-arc furnace used in the continuous casting of steel.

Very early railway lines cast in 1767 leads up, through the stages of 30-ft. and 60-ft. rails, to the modern laying and welding of 300-ft. lengths into continuous track on British Railways.

Some fine examples of old steam engines still in use are shown, the four beautiful beam engines with their 8-ton flywheels working at 200 i.h.p. and 11 r.p.m. at Leicester Sewage Works is followed by the three-cylinder vertical steam engine at Dorman Long's Britannia mill, which is of 16,000 i.h.p. and has outstanding acceleration necessary in the powering of the rolling mill. After visiting the beam mill at Lackenby and the new steel works of Richard Thomas and Baldwins in South Wales, the winning of ironstone at Corby by a giant dragline weighing 1,650 tons is seen, its 27-ton bucket removing the overburden at the rate of 1,600 tons every hour.

Examples of the use of steel in modern buildings, bridges, railway electrification and a floating island of steel concludes the film. One criticism—although the film does not set out to be in any way a comprehensive survey we should, I feel, have been shown at least a glimpse of steel actually being made.

'An Industrial Notebook on Iron and Steel,' made by Random Film Productions Ltd., is in black and white and available in 35 mm. and 16 mm. through the Shell-Mex and B.P. Film Library from June 1. Duration at 24 f.p.s. is 27 min. 48 sec.



Continuous casting of steel at Barrow Steel Works. The casting speed averages 20 ft. min.



## A new high-temperature alloy

*Devised for service above 980°C., this new nickel-base alloy, known as RA-333, contains 25% chromium and 3% each of molybdenum, cobalt and tungsten. Its excellent creep-rupture properties, low coefficient of expansion and good oxidation resistance make it useful for critical parts in heat-treating furnaces. The following account is based on an article in 'Metal Progress,' February, 1961, by Mr. John Maxson, Rolled Alloys Inc., Detroit, U.S.A.*

BUILDERS AND USERS of high-temperature furnace equipment continually demand better materials for their muffles, retorts, radiant tubes, fixtures and related furnace parts. The procurement of a material to answer this need might seem relatively simple, particularly since there are a number of excellent superalloys already available. However, it must be borne in mind that most of these new alloys are produced in limited quantities by special techniques and, under these circumstances, some new sort of high-temperature alloy seemed to be called for.

As a general-purpose alloy for use in a broad temperature range, the new alloy—RA-333—was built to definite specifications. It was to have good strength above 980°C., adequate resistance to oxidizing, carburizing, nitriding and other atmospheres, along with reasonable fabricability. Cost and availability was also considered.

### The new specification

The first step was to survey all known existing alloys to evaluate their chemical compositions, along with their mechanical properties at temperatures and in atmospheres which they might encounter. Next we 'blueprinted' a new alloy as we thought it might exist. To explain further, since oxidation resistance is most effectively promoted by chromium, it was decided to add as much of the element as possible. However, forgeability is a limiting factor, so an arbitrary limit of 25% Cr was fixed. Since a further reduction in iron content was desired (for improved oxidation resistance), 45% Ni was included in the tentative formula. Here the strength reduction which occurs when nickel content is increased was a limiting factor. Nickel adds corrosion resistance, ductility, low coefficient of expansion and resistance to thermal shock. In addition, it was thought that a relatively high percentage of nickel would probably promote forgeability and grain refinement, even

though some strengthening elements would be required.

In conventional heat-resisting alloys, silicon promotes oxidation resistance and, even to a greater degree, resistance to the carbon and nitrogen found in furnace atmospheres. However, since silicon has little added effect over 1.5%, it was limited to a nominal 1.25%.

The strengthening elements which could be used included tungsten, molybdenum and cobalt. Of these, molybdenum is probably the most potent for high-temperature strength, but it was decided to limit it to avoid hazards of catastrophic oxidation. Cobalt, if required in very large amounts, appeared too costly. Although recognizing the strengthening effect of tungsten, the cost and possible influence on oxidation resistance, stability of the alloy and forgeability required more investigation.

### Laboratory work

Finally, laboratory heats were tried with the basic nickel, chromium, and silicon contents already established. Varying amounts of the three strengthening elements, molybdenum, tungsten and cobalt, were added singly and in combination and the resulting alloys were evaluated on the basis of their short-time mechanical properties at high temperatures.

While forging and rolling all heats into 1-in.-dia. bars, their hot-working properties were closely observed and compared. From the test specimens machined from these bars, it was determined that the three strengthening elements gave better results in combination with each other than singly in larger quantities. Therefore, a nominal 3% W, 3% Mo and 3% Co mixture was established for the alloy. Currently produced as a commercial material, it contains 45% Ni, 25% Cr, 1.25% Si, 3% W, 3% Mo, 3% Co and 0.08% max. C. All harmful residuals are carefully restricted and limited in general to 0.03%. Some mechanical

properties are shown in Tables 1 and 2. Stress-rupture values at 100 h. were:

Temperature, °C.	Stress, lb./sq. in.
730	23,000
760	18,500
790	14,500
815	10,500
845	9,050
870	7,200

When the first large heat was produced (in April, 1958), it immediately became evident, from the forging difficulties encountered, that we had accomplished our original objective of improved creep and yield properties at high temperatures.

TABLE 1 Mechanical short-time properties of RA-333

Temp., °C.	Tensile, lb./sq. in.	Yield, lb./sq. in.	Elongation in 2 in., %	Reduction of area, %
Room ..	105,000	55,000	55	62
980 ..	16,500	—	40	35
1,065 ..	10,000	—	45	35

TABLE 2 Stress-rupture properties

Temperature, °C.	Stress, lb./sq. in.	Time of rupture, h.	Elongation in 2 in., %
760 ..	21,600	22.0	47
815 ..	16,600	9.7	61
870 ..	16,000	9.4	64

From this first heat, we obtained enough alloy to fabricate test equipment for field evaluation.

The alloy was first evaluated for oxidation resistance in the 1,200° C. range. When it exhibited excellent properties, several interested companies initiated a series of tests which indicated that the alloy offered considerably improved stress-rupture properties, compression yield strength, tensile yield strength and stress oxidation resistance. Limited creep data have been determined at 1,200° C. with promising results.

Service tests also indicated that it had a very good resistance to thermal fatigue. An unforeseen benefit promoted this property, since the new alloy proved to have a lower coefficient of expansion ( $8.85 \times 10^{-6}$  in the 20-980° C. range) than conventional heat-resisting alloys.

### Applications

The new alloy was developed with the expectation that it would be applied where temperatures of 980° C. or higher were met. For example, it could be used in high-temperature carburizing furnaces and some aircraft and missile brazing processes. However, high-temperature carburizing has not been accepted as extensively as was originally

hoped for. Furthermore, the more conventional alloys have performed better than anticipated in inert atmospheres and oxidizing environments encountered at the 1,230° C. temperatures used in brazing.

As interest in the new alloy increased, engineers began to test it for baskets, fixtures and radiant tubes in carbo-nitriding and carburizing furnaces, as well as other conventional applications. When used below 980° C. it is not significantly superior in short-time physical properties to more conventional alloys, but its greater creep strength and resistance to thermal shock may make it quite useful. As an example, corrugated carbo-nitriding boxes fabricated from the alloy have lasted three times as long as similar boxes made of the best previously used materials. They still show very little sign of deterioration. Radiant tubes and highly stressed furnace components such as circulating fans and conveyor chains have indicated a comparable increase in life expectancy.

### Economic factors

Some practical considerations concern cost and availability. Since the new alloy is produced by conventional arc-melting practice in large heats, its cost is less than alloys requiring vacuum melting. It can be annealed, rolled, formed and welded without highly specialized facilities, and it is readily available. Good, sound ductile welds are obtainable by standard arc welding techniques. Although it is not free machining, neither are other work-hardenable heat-resistant alloys.

### Giant electric-arc melting furnaces

G.W.B. Furnaces Ltd., of Dudley, Worcs., have now received orders to build four giant electric-arc melting furnaces as part of Steel, Peck & Tozer's £10,000,000 development programme. The total order is the largest of its kind in the world.

A year ago G.W.B. were awarded a contract from Steel, Peck & Tozer to build two of these electric-arc melting furnaces which will be almost twice as large as any previously built in Great Britain. The Dudley company has now received an extension to this order.

The steel construction will be carried out by the United Steel Companies' own subsidiary company, Distington Engineering Co. Ltd. Total output of the finished plant will be 1,135,000 ingot tons of steel a year.

The electrical demand of the four furnaces will be equivalent to that of a town the size of Wolverhampton. Each has an electrical rating of 40,000 kVA.

The furnaces are entirely British built and engineered, the basic mechanical design being that of Demag-Elektrometallurgie. They have a nominal capacity of 150 tons, but they will be worked with a 110-ton charge in order to have a shallow bath, with a large surface area; this technique is considered by some metallurgists as a better way of making steel, rather than having a deep bath and smaller surface area for a given tonnage capacity.

## NEWS

**Institute of Metals**

THE FOLLOWING MEMBERS have been declared elected to fill vacancies that will occur on the Council of the Institute of Metals at the annual general meeting on March 21:

**President:** Prof. H. O'Neill (head of the Department of Metallurgy, University College of Swansea, University of Wales).

**Past-president:** Sir Ronald Prain, O.B.E. (chairman and president, Rhodesian Selection Trust Ltd.).

**Vice-presidents:** Mr. W. F. Randall (deputy chairman and managing director, Telcon Metals Ltd.) and the Right Hon. the Earl of Verulam (chairman, Enfield Rolling Mills Ltd.).

**Ordinary members of Council:** Mr. N. I. Bond-Williams (managing director, The Aston Chain and Hook Co. Ltd.); Prof. A. H. Cottrell, F.R.S. (Goldsmiths' Professor of Metallurgy, University of Cambridge); and Mr. G. A. Rider (deputy managing director, Birmid Industries Ltd.).

The Council has elected the Earl of Verulam to serve as senior vice-president for the year 1961-62.

**More tonnage oxygen for Spencer Works**

A third 200 tons a day oxygen plant is being built by the British Oxygen Co. Ltd. for Richard Thomas & Baldwins Ltd., for their new steelworks near Newport, Mon. The new plant is scheduled to be ready for operation early in 1963. It brings the total daily capacity of plant to be installed and operated by BOC at Spencer Works to 600 tons of high purity oxygen. The two first 200-ton plants are scheduled to be ready for operation towards the end of this year. Spencer Works is now being prepared for the third unit and planning has started on the fabrication of the plant at Edmonton.

**6½-ton spun pressure vessel head at Leipzig Fair**

THE MAIN EXHIBIT of G. A. Harvey & Co. (London) Ltd. showing at the Leipzig Fair is a large spun pressure vessel head, dished and flanged from 1½-in. thick stainless steel 'Colclad' plate. The head is of ellipsoidal shape with an inside diameter of 12½ ft. and it has a machined edge which has been etched to show the stainless steel corrosion-protecting surface to the thick carbon steel plate. It weighs 6½ tons.

The head was formed on a 'Rotapress' machine, of which there are two examples in Britain. This machine is capable of forming and finishing heads up to 15 ft. dia. and 4 ft. thick. The use of this machine's spinning process enables Harvey's to produce one-piece heads conforming to the deep shape with large knuckle radii as required by pressure vessel designers in all countries and conforming to modern design codes.

At Leipzig, Harvey's exhibit—which also includes a model of a jet-engine test plant supplied to Rolls-Royce for which Harvey's were responsible for the design, fabrication, erection of test cells, pressure vessels and ducting—forms part of the composite British Chemical Plant Manufacturers' Stand.

The spun end exhibit typifies the size and nature of Harvey's products; the company has manufacturing facilities for pressure vessels and welded fabrications of up to 150 tons in weight.

Scheduled to start production early next year, the Spencer Works will be first in the world to make steel exclusively by the L.D. oxygen process. There will be three 100-ton L.D. converters. In addition to piping oxygen from their tonnage installation to feed the steel furnaces, British Oxygen will supply substantial quantities of high-purity nitrogen-hydrogen mixture for the annealing furnaces.

**Club for retired employees**

At the forging works of Garringtons Ltd. (Bromsgrove and Darlaston) the chairman, Mr. R. P. Brookes, has made the welfare of long-service employees his personal concern. For all retired members of Garringtons with 25 years' service and over he has created, at the company's Darlaston works, a lounge for their use at any time of the day. The room, to be known as the 'Evergreen Club,' is fitted out by one of Birmingham's leading furnishes with contemporary-styled easy chairs, fully fitted carpet, central heating and wall-mounted electric fires, mahogany wall panelling and book-shelves, television, radio, etc. Close at hand is the staff canteen and bar, so that the 'residents' can obtain refreshments at any time.

**Change of name**

The Mond Nickel Co. Ltd., an affiliate of the International Nickel Company of Canada Ltd., announces that its name is now the International Nickel Company (Mond) Ltd.

In announcing the proposed change of name the chairman, Mr. Ivon A. Bailey, said that it did not involve any change in the company's organization or in its business activities. The board, in consultation with the



International Nickel Company of Canada Ltd., the parent company, took the view that the change of name would, in addition to indicating the international nature of the company's activities, serve to identify it more closely with the Canadian company and the United States affiliate, the International Nickel Company Inc.

#### Exhibition of modern industrial metals

The International Nickel Company (Mond) Ltd. are presenting an exhibition at the Engineers' Club, Albert Square, Manchester, designed to interest all concerned with engineering problems involving the use of metals.

The main emphasis of the exhibition will be upon the properties of nickel-containing materials and the platinum metals. For convenience the exhibits, displays and demonstrations will be divided into seven sections relating to: the properties of metals at high, normal and sub-zero temperatures; metals versus corrosion; metals for surface protection; metals with special magnetic, expansion or chemical properties; methods of fabrication. Another section will feature nickel and chromium plating to the new British Standard. Lectures will be given by members of the company's development and research department, and films will be shown.

#### F. J. Stokes Corporation establishes British subsidiary

F. J. Stokes Corporation, of Philadelphia, Pennsylvania, has established a subsidiary company in Great Britain. Incorporation of F. J. Stokes Ltd., with headquarters in London, has been announced. The new British subsidiary will manufacture some of Stokes' range of machines and equipment for the plastics, chemical, pharmaceutical, automotive, electronics and food industries. These machines will be available throughout the British Isles, the Commonwealth, and countries of the European Free Trade Association.

Directors of the new subsidiary are Allan A. Hutchings, vice-president in charge of sales, and F. Joseph Stokes, Jr., vice-president in charge of manufacturing for the American company, and Malcolm Scott of London.

James T. Davies, an Englishman and a former sales engineering executive of the American company, has returned to London to undertake the general management of operations for F. J. Stokes Ltd. He will direct production, sales and on-the-spot technical service throughout the United Kingdom.

British manufacture of Stokes' equipment is already under way in association with Thomas White & Sons Ltd., of Paisley, Scotland, an experienced builder of industrial machinery founded in 1863.

#### LECTURES

**Borough Polytechnic, Borough Road, S.E.1**  
DIVISION OF METAL SCIENCE

*Symposium on 'welding of rarer metals':* Thursday, April 20, morning and afternoon. Programme includes electron beam welding; welding of beryllium, uranium, titanium, zircaloy 2, tantalum, niobium, molybdenum and tungsten.

*Symposium on 'internal stresses in electrolytically produced coatings and their effects on the properties of the basis metals':* Thursday, July 6, morning and afternoon. Programme includes internal stresses and their measurement; internal stresses in hard chromium and heavy nickel deposits, in bright nickel deposits, in rhodium and platinum metal deposits, and in electroforming and electrotyping.

#### Battersea College of Technology

METALLURGY DEPARTMENT

*The fracture of metals.* April 11-14.

The course, of 3½ days' duration, is intended to give an overall picture of recent work in this field. All the lecturers have been selected for their first-hand knowledge of the subject. The topics to be covered will include: the practical problems of fracture in service; mechanical testing methods for the assessment of fracture behaviour; theoretical aspects of fracture; the ductile to brittle transition in ferrous and non-ferrous metals; the effect of irradiation on fracture behaviour; temper brittleness in steels; hydrogen embrittlement of metals; fracture under creep conditions; and fracture under fatigue conditions.

Fee £10 10s. (inclusive of luncheon, morning and afternoon refreshment). Enrolment forms may be obtained from the Secretary (Metallurgy Courses), Battersea College of Technology, London, S.W.11.

#### CRYSTALLOGRAPHY SECTION

*Applications of electron diffraction.* April 13-14.

This course has been arranged for users and potential users of electron diffraction techniques in science and industry. The emphasis will be on practical applications rather than theoretical aspects of the subject. In view of this, the first day of the course will be devoted to lectures and discussion, while on the second day visits will be arranged to establishments where electron diffraction apparatus is in use.

Fee £5 5s. (inclusive of luncheon, morning and afternoon refreshment and transport for visits). Enrolment forms may be obtained from the Secretary (Crystallography Courses), Battersea College of Technology, London, S.W.11.

### NOTICE TO ADVERTISERS AND AGENTS

It is greatly regretted that owing to acute lack of space, both at our offices and at our printer's works, it is not possible to retain in store indefinitely obsolete blocks used in past advertisements in 'Metal Treatment.'

**Notice is therefore given** that we shall be obliged to dispose of all advertisement blocks that have not appeared in the journal since **December, 1957**, if no application has been received for their return on or before **May 1, 1961.**

'Metal Treatment,'  
John Adam House,  
17-19 John Adam Street,  
London, W.C.2.

March 15, 1961



## PEOPLE

THE COUNCIL of the Institute of Metals announces the following awards of medals for 1961:

The Institute of Metals (Platinum) Medal to Major C. J. P. Ball, D.S.O., M.C., F.R.A.E.S., F.INST.MET., chairman, Magnesium Elektron Ltd., in recognition of his outstanding services to the non-ferrous metal industries and, in particular, to the magnesium industry.

The Rosenhain Medal to Dr. P. B. Hirsch, of the Cavendish Laboratory, Cambridge, in recognition of his outstanding contributions in the fields of physical metallurgy and metal physics.

**Major Charles James Prior Ball**, born in 1893, was educated at Charterhouse and the University of London.

In 1923 he retired from the Army and, following his return to the United Kingdom, joined the firm of F. A. Hughes & Co. Ltd., and pioneered in Britain the first real usage of the important light magnesium alloys developed by the Germans. He took the initiative in the formation of Magnesium Elektron Ltd., and, as its chairman and managing director, was responsible for the erection of a factory at Clifton Junction, near Manchester, the first unit of which went into production towards the end of 1936, and the second unit some eighteen months later. With the outbreak of war in 1939, the demand for magnesium went up rapidly and the plant at Clifton Junction was doubled in 1940. In 1942, a factory was erected near Burnley of rather larger capacity than the enlarged Clifton Junction plant. In 1941, Major Ball advised the U.S. Government on the problem of how to increase production rapidly. The U.S. Government asked Magnesium Elektron Ltd. to provide plans to train personnel to erect and operate the largest magnesium plant in the world near Boulder Dam in the Nevada Desert.

After the war although the demand for magnesium fell back to the pre-war level, Major Ball's faith in the future of magnesium was such that he negotiated the purchase by his company of much of the Government stockpile. Before the war the effect of zirconium on the properties of magnesium had been known but no method had been evolved which enabled usable alloys to be made. Since the early days, Major Ball, realizing the benefits which would result if the problem could be solved, continued to support this research, and success came at a time when aircraft designers were in need of strong light alloys capable of operating at elevated temperatures. As a result of these developments M.E.L. now holds a unique international reputation in the magnesium industry.

**Dr. P. B. Hirsch** started his research career in the Cavendish Laboratory, Cambridge, in 1946, when, in collaboration with the late Mr. J. N. Kellar, he developed an X-ray micro-beam technique to study the fine structure of cold-worked metals. The subsequent investigations on a variety of metals showed that the fragmentation of the individual grains to form sub-grains was a common feature of plastic deformation. These X-ray studies led to valuable information on the distribution of dislocations in the cold worked state, and also threw light on the phenomena of recovery and recrystallization.

In 1954, realizing that the newly developed high resolution electron microscope might be applied to a study of deformed metals, Dr. Hirsch initiated work on the examination of metal foils, so thin that they were transparent to the electron beam. This work quickly confirmed many of the results obtained with the X-ray micro-beam, concerning the formation of sub-grains.

However, the most important and impressive observations were those which directly revealed the existence of dislocations, both in annealed and deformed metals. Dr. Hirsch and his colleagues were able not only to observe individual dislocations in the foils, but also to study their movement and their interactions with each other. The striking electron micrographs made on aluminium and stainless steel are now widely known and represent a landmark in the development of physical metallurgy.

By the careful interpretation of numerous observations, Dr. Hirsch showed that dislocations possessed many of the properties which had been predicted theoretically, as well as some new features of considerable interest. The scope of the work was extended to include metals deformed in various ways, e.g., at elevated temperatures and by fatigue, and also the defects introduced by quenching from high temperatures. At the same time Dr. Hirsch was not content to accept the pictures of dislocations at their face value, but initiated work designed to interpret the various diffraction effects which were apparent in the electron micrographs.

In recent years, Dr. Hirsch has also taken a considerable interest in the basic mechanical properties of metals, and by analysis of results on the temperature dependence of stress-strain curves of single and polycrystalline pure metals, he has made a substantial contribution to the theory of work hardening. In addition, he has helped to stress the importance of stacking faults in close-packed metal structures. Moreover, he has made a close study of the stacking fault energies of metals and how they are influenced by alloying.

Wild-Barfield Electric Furnaces Ltd. have carried out some internal reorganization and made some new appointments from within the company. The appointments are: Executive manager (engineering), Mr. W. R. Brew; executive manager (commercial), Mr. F. L. Gladwin; executive manager (production), Mr. O. V. Metcalfe; and sales manager, Mr. R. C. Ray.

**Mr. W. R. Brew** commenced his career with Wild-Barfield Electric Furnaces Ltd. in 1934 as a student apprentice. He served in various sections of the company before being moved to the Sales Department in 1937. He was appointed home sales manager in 1946 and sales manager shortly afterwards.

**Mr. F. L. Gladwin.** After receiving a Diploma in Electrical Engineering from Northampton Engineering College, Mr. Gladwin commenced his career with the Fuller Electrical and Manufacturing Co. Ltd. as a technical assistant in the Welding Sales Department, moving in 1937 to take up a similar post with G. D. Peters & Co. Ltd. He later went to the Arc Manufacturing Co. Ltd., subsequently taken over by Wickman Ltd., and was seconded to Applied High Frequency Ltd. as technical sales manager. This latter company was acquired by Wild-Barfield Electric Furnaces Ltd. in 1955, and Mr. Gladwin was appointed sales manager (Induction Heating Division). Later his responsibility was increased to take in the Vacuum Division.

**Mr. O. V. Metcalfe.** Originally served his apprenticeship with Bull Motors, of Ipswich. After spending some time in the Signal Division of London Electric Railway, Mr. Metcalfe joined Wild-Barfield Electric Furnaces Ltd. in 1933 as assistant works manager, being appointed works manager in 1938. Among his other activities are those of being a governor of Watford Technical College and a director of Watford Metal Fabrications Ltd.

**Mr. R. C. Ray.** In July, 1937, Mr. Ray joined



Wild-Barfield Electric Furnaces Ltd. and entered the Design and Drawing Office. He continued his technical education at the Northampton Polytechnic in London until commencing his service with the R.A.F. in 1942. After qualifying as a navigator, Mr. Ray served in the Middle East theatre of operations, being awarded the D.F.M. and subsequently being commissioned. Upon being demobilized in 1946 he rejoined the company and moved to the Sales Office, of which he was appointed manager in 1957.

Dudley Drop Forging Co. Ltd. announces the retirement of the commercial manager, **Mr. M. L. Hackett**, who had been associated with the company in various executive capacities since 1940. Mr. Hackett, owing to his wife's continued ill health, felt unable to carry on with his duties.

Dudley Drop Forging Co. Ltd. has announced the election to the board of **Mr. Charles D. Garner** and **Mr. Geoffrey Race**, who have hitherto been engaged in the capacities of works manager and secretary respectively.

Shell-Mex and B.P. Ltd. announce the following appointments: Mr. A. C. Durie to be general manager, Industrial Sales. Mr. E. Rendall to be assistant general manager, Industrial Sales.

**Mr. Durie**, who joined the company in 1933, has been general manager, Administration, since 1957; before that he was marketing director of the Shell Co. of Australia for three years.

**Mr. Rendall**, former manager of the company's North-Eastern Division, was appointed sales manager, Industrial Fuels, in July, 1960.

**A. Nadin**, A.M.B.I.M., A.M.I.W.M., general manager, Brayshaw Furnaces Ltd., and Brayshaw Tools Ltd., Belle Vue Works, West Gorton, Manchester, 12, has been appointed a director of both of the above companies.

**Mr. K. Clark** has been promoted to the new position of assistant export manager, Acheson Colloids Ltd., a subsidiary of Acheson Industries (Europe) Ltd. This appointment, effective from April, is the first step in an expansion programme designed to increase overseas outlets for the 'dag' range of dispersions.

Mr. Clark joined the Acheson Organization seven years ago. After several years as a senior engineer concerned with both U.K. and export sales development, he was transferred to Acheson Dispersed Pigments Company as sales supervisor three years ago. Mr. C. R. Wills, general manager of Acheson Colloids Ltd., will temporarily assume the additional responsibilities of export manager.

**Mr. R. S. Falk**, O.B.E., deputy chairman of the Provincial Insurance Co. Ltd., and a director of Production-Engineering Ltd. (management consultants), has been appointed to the Council of Industrial Design for a further period of two years. Mr. Falk has been a member of the council for the past three years.

**Mr. R. P. Newman**, A.M.I.MECH.E., has been appointed head of the Members' Service Department of the British Welding Research Association in succession to Mr. P. H. R. Lane, now director of research of the Drop Forging Research Association. **Mr. T. R. Gurney**, M.A., A.M.I.C.E., will succeed Mr. Newman in charge of fatigue researches at B.W.R.A.

**Mr. Russell Smith** has been chairman of Stein & Atkinson Ltd. for 10 years. He has now retired and

**Mr. H. W. Howes** has been appointed chairman in his place. Mr. Howes has been a director of Stein & Atkinson Ltd. for the last 11 years.

**Mr. J. W. Haig-Ferguson**, M.A., A.M.I.MECH.E., A.M.I.E.E., A.M.I.PROD.E., has recently been appointed managing director of R. & J. Beck Ltd., 68-71 Mortimer Street, London, W.1, one of the Griffin & George group of companies, and manufacturers of optical instruments.

Mr. Haig-Ferguson, born in 1923 in Edinburgh, was educated at Wellington College and Queens' College, Cambridge. After varied industrial experience in the technical and production side of industry, he was appointed divisional director (electronics) of Bruce Peebles & Co. Ltd.

**Mr. Justus Sjögren**, chairman of Sandvik Swedish Steels Ltd., Halesowen, Birmingham, and Sandvik Steel Band Conveyors Ltd., Selly Oak, Birmingham, died last month, at the age of 82.

Mr. Sjögren came over to this country in 1901 and pioneered the development of the Sandvik Organization in Great Britain. He was chairman and managing director of Sandvik Swedish Steels Ltd. from 1914 until 1947, when he left the latter post but continued as chairman, and was chairman of Sandvik Steel Band Conveyors Ltd. from 1921.

Mr. Sjögren formed strong personal relations with Birmingham and was, in fact, Consul for Sweden in Birmingham from 1920-1948. He was awarded the Order of Wasa and the Order of Nord Stjärnan (the Order of the North Star) for his contribution to the Anglo-Swedish trade and cultural relations.

**Mr. C. Vickers**, A.M.I.E.E., A.M.I.MECH.E., has been appointed general sales manager of Ferro Enamels Ltd.

Mr. Vickers, a native of Sheffield, was educated in Nottinghamshire before becoming apprenticed to the General Electric Company Ltd., Witton, Birmingham. He resided in that city for several years graduating to chief engineer of a group of companies engaged in steel and non-ferrous metal processing.

He subsequently served in the administration of German industries in the Ruhr, before joining the British Aluminium Company Ltd., with whom he had charge of a subsidiary manufacturing company in India following partition.

His introduction to the enamelling industry came with his appointment as chief executive officer of a prominent manufacturer of holloware and associated products in the Midlands. Since that time he has taken a keen interest in the promotion of vitreous enamel.

In his capacities of director of the Vitreous Enamel Development Council, and vice-chairman of the Hardware Manufacturers Association, he has been prominently concerned in publicizing enamelled products. In recent times he has pioneered the manufacture and promotion of enamelled aluminium in this country, having put down and operated the first purpose-built plant.

The Firth Cleveland Group announces the appointment of **Mr. Graham Cooke** as group publicity director to head a new division which will co-ordinate and control advertising and public relations for the group and all its member companies.

For the past four years Mr. Cooke has been publicity director of the Solartron Electronic Group which is now part of the Firth Cleveland group of companies. He remains a director of Solartron. Before joining Solartron he was a director of S. C. Peacock Ltd., advertising agency, and was also for several years with Foote, Cone & Belding Ltd.

Electrical Aids in Industry

Data Sheet **No. 15****Electric Motors & Controls-2**

Control equipment must enable the motor to be operated effectively, to obtain maximum productive efficiency. An outstanding advantage of individual electric drives is the flexibility of control available. Control equipment may be manual, semi-automatic or fully automatic, and includes gear for the following operations: starting, speed control (this subject will be dealt with in Data Sheet No. 16), reversing, stopping, switching off automatically if operating conditions become abnormal and isolation of motor and control equipment from the supply.

Every application of power has its own control requirements—and they are legion. Below are featured four uses of electric motors and their controls; they are given only as examples and represent but a small fraction of the whole picture.

**Turret-lathe Control**

Various speeds are required for different tools, and it is possible to arrange, for instance, for a four-speed headstock, forward and reverse. By using a two-speed double-wound motor, eight speeds forward or reverse are obtainable. A dial on the headstock is set to the required speed and when a knob in the centre of the dial is pressed, the power-operated mechanism changes the speed of operation instantly.

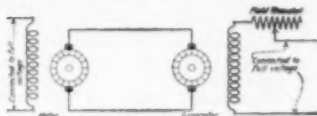
**Crane Control**

This is a form of control which must be flexible yet completely foolproof. It is, for instance, possible to arrange for motor switching to be carried out by the contactors in response to movement of the crane driver's master controller. If the crane controller is moved quickly from the 'off' position to the 'last point lowering', the actual rate of acceleration is limited automatically by the relays. These also govern the retardation in order to prevent a heavy descending load being stopped too suddenly.

**Planing-machine Control**

Another example of motor control for machine tools is that for planing machines. For general workshop machining, the Ward-Leonard controlled motor, with a

speed range of 10 to 1, gives a rapid and smooth reversal of the table travel and is ideally suited for short-stroke work. Two arrangements of Ward-Leonard control are available, the 3-machine



set with generator, exciter and driving motor, and a specially designed 4-machine set with an additional auxiliary exciter. With the 3-machine set the control equipment can include magnetic time relays which automatically adjust a regulator to strengthen the motor field at the instant of reversal and therefore greatly increase the accelerating torque. The auxiliary exciter of the 4-machine set automatically provides for the power input to the motor to be increased to give more accelerating torque at the instant of reversal.

**Automatic Control**

The control equipments described incorporate automatic features which help considerably towards obtaining safe and efficient operation of the driven machine, but much still depends on the human element. Braking equipment, for instance, cannot always become effective until an operative has taken some action. Devices, which will be described in other Data Sheets, 'observe' any abnormal condition and immediately and automatically initiate the braking system.

Particular attention should be paid to the positioning of controls. When a machine, or group of machines, requires a large number of push buttons and, in some cases, instruments etc., the controls can all be grouped on a desk with a mimic diagram, located in a position where the operator has full view of the work.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London W.C.2. TEMple Bar 9434.

They can offer you excellent reference books on electricity and productivity (8/6, or 9/- post free) — 'Electric Motors and Controls' is an example.

E.D.A. also have available on free loan within the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

79-1-A

## NEW PLANT

### Ceramic insulating brick at temperatures up to 2,320 C.

Ipsen Industries Inc. announces a new ceramic insulating brick that withstands temperatures to 4,200 F. (2,320° C.). The material, developed at its Ceramic Division at Pecatonica, Illinois, is known as I.C.B.4200. It is being formed in standard brick sizes of 2½ by 4½ by 9 in. Among its outstanding properties is a mean thermal conductivity at 2,200 F. (1,205 C.) of less than 1.0. It has an 89% porosity and each brick weighs approximately 2 lb.

Basically, I.C.B.4200 is a formulation of zirconium oxide material, expanded and fired. A cellular structure consisting of uniform open pores with all cells interconnected permits gas to pass through for purging or evacuation. This porosity will also permit the passage of liquid. Its melting point is 4,620 F. (2,550 C.). It has a temperature limit (hot face) of 4,200 F. (2,320° C.) in oxidizing atmosphere, in nitrogen, and in hydrogen atmosphere. Other hot-face temperature limits include 4,200 F. (2,320 C.) under vacuum conditions, 3,000 F. (1,650 C.) in a reducing atmosphere with carbon present, 2,200 F. (1,205 C.) in contact with SiC, 3,000 F. in contact with SiO<sub>2</sub> or Al<sub>2</sub>O<sub>3</sub>. This material is readily cut, sawed or filed.

This insulating ceramic material is expected to have applications in the nuclear field as well as in the space vehicles field. In the metallurgical field it has immediate acceptance for very high temperature applications. I.C.B.4200 is presently being used in a combination vacuum-atmosphere furnace operating at 4,200 F. for sintering of high temperature materials. Current production rates are on a laboratory basis. Ipsen Industries Inc. is represented in the U.K. by Mr. T. W. Ruffle, 53 Victoria Road, Surbiton, Surrey.

### Spark machining

Wickman Ltd. announces that under an agreement recently concluded with Ateliers des Charmilles, S.A., Geneva, the company becomes the sole selling agency in the United Kingdom for the Eleroda Model D.1 Electro-Erosion Machine.

The Eleroda machine is already well known in this country as a high-precision spark-machining unit particularly designed for tool-room applications, and its addition to the Wickman range will complement the present range of Erodomatics manufactured by the company.

The range of Wickman Erodomatics now available comprises: Type W/BM: A bench- or cabinet-mounted machine incorporating vernier positioning to the electrode head and designed for spark machining high-precision components of small size. Type W/SM: A self-contained medium-size machine with simplified controls, specifically designed for production use. Type W/DM: The recently introduced large capacity die machine available with 4.5 kW. or 13 kW. power pack and designed for the machining of heavy forging dies.

The range is handled by the Wickman Electro-Mechanical Department, Upper York Street, Coventry.

### Electrically-heated salt bath furnaces

Five new types of electrically-heated furnaces are now being added to ICI's range of oil- and gas-fired 'Cassel' furnaces. Made by the company's General Chemicals Division and sold both in this country and in a number of overseas territories under exclusive licence from the Ajax Electric Co., Philadelphia, U.S.A., they are available in various sizes.

Three of the new types, known as the 'Cassel' Ajax

S.R., S.S. and Q., are electrode-heated furnaces with rectangular pots. The salt in the pots is heated by current passing between electrodes immersed in the salt, and the life of the pot is therefore far longer than that of pots heated externally by gas or oil. Continuous operation is recommended.

'Cassel' Ajax S.R. furnace: Used for heat treatment with neutral salts in the temperature range 700–1,000° C. The pot is made of interlocking refractory bricks and should last from one to three years.

'Cassel' Ajax S.S. furnace: Used for carburizing with various salts containing cyanide in the temperature range 650–1,000° C. The pot is made of mild steel plate and should have a life approaching one year.

'Cassel' Ajax Q. furnace: Used for quenching and secondary hardening of high-speed steel in the temperature range 500–700° C. The pot is made of mild steel plate and should last up to two years.

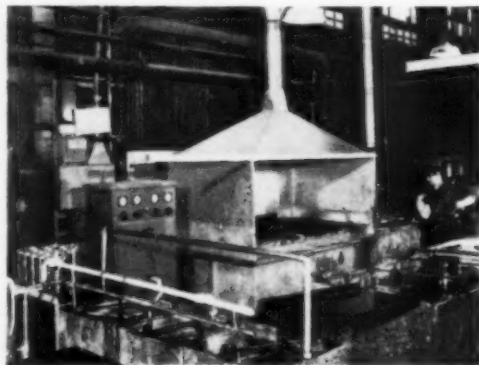
The two remaining 'Cassel' Ajax furnaces, the T. and T.I.Q. types, for lower-temperature working, are fitted with immersion heaters. Here the heat is produced in resistance elements immersed in the salt and suitably protected. So in these furnaces also, the pot does not have to transmit heat, and should last several years.

'Cassel' Ajax T. furnace: Used for tempering steel and heat treating aluminium alloys in the temperature range 160–400° C. (special furnaces for temperatures up to 500° C. are available). The pot is made of mild steel and should last four to five years.

'Cassel' Ajax T.I.Q. furnace: Used for quenching steel during austempering or martempering treatments. Agitation of the salt bath is arranged so that parts being quenched are exposed to a uniform flow of molten salt which extracts heat rapidly and with minimum distortion of the work. The pot is air cooled externally to prevent the salt rising in temperature. If parts have just been austenitized in a high-temperature salt bath a separating chamber is provided in which the high-temperature salt is removed.

'Cassel' Ajax furnaces offer all the accepted advantages of salt baths. Work is produced with a clean, scale-free finish. Results are uniform and can easily be reproduced. The furnaces themselves are clean, silent and simple to operate.

A 'Cassel' Ajax electric furnace with pot 58 × 20 × 20 in.



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'BRADLEY' 100-LB. FORGING HAMMER for sale. Depth of gap 12 in. Rubber-cushioned blow. 4-in. whip stroke. Complete with anvil. F. J. Edwards Ltd., 359 Euston Road, London, N.W.1, or 41 Water Street, Birmingham, 3.

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*Literature on request from Manufacturers*

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Photograph by courtesy of Messrs.  
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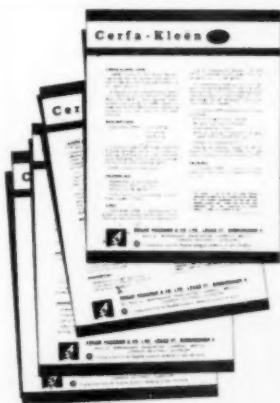
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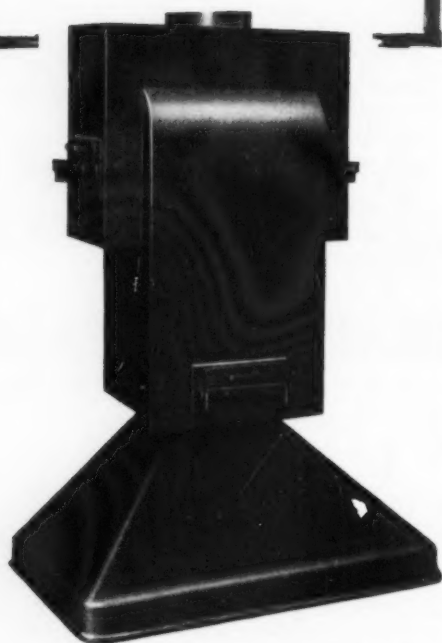
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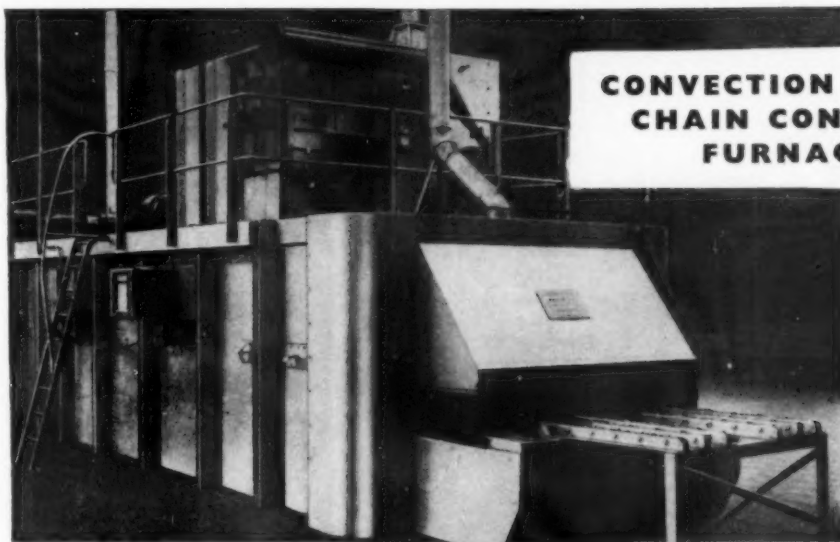
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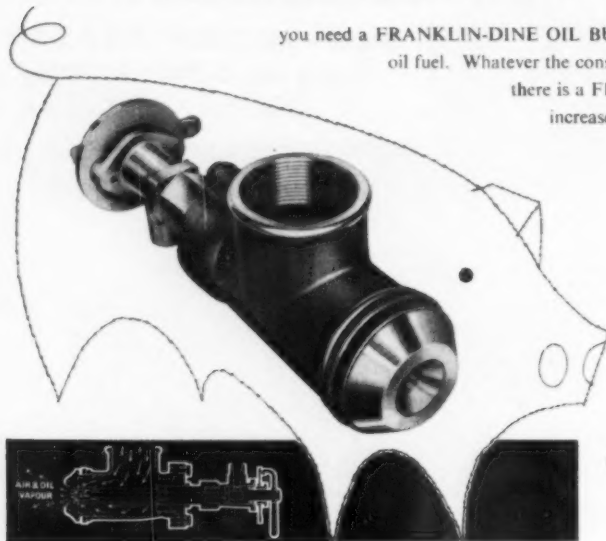


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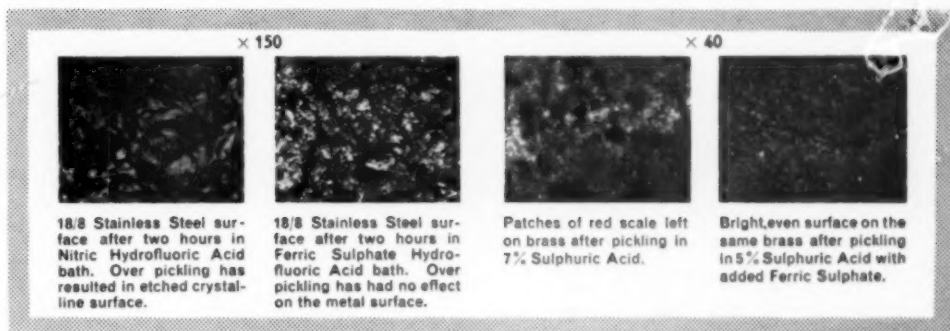
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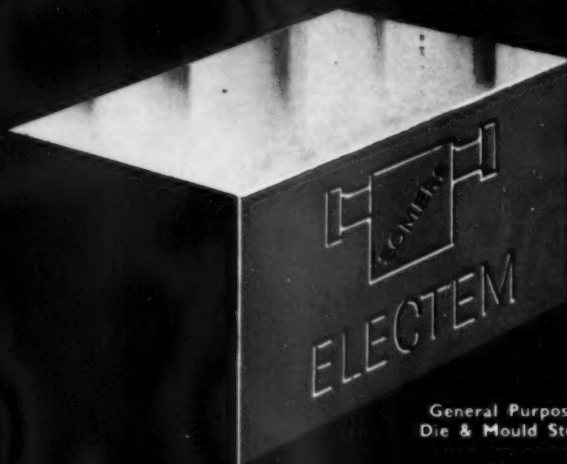
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